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AND EXPERIMENTS, PROCURES KNOWLEDGE FOR MEN"—SMITHSON

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CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

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SMITHSONIAN MISCELLANEOUS COLLECTIONS

VOLUME 68 NUMBER 1

Archeological Investigations in New Mexico, Colorado, and Utah

(WITH 14 PLATES)

BY

J. WALTER FEWKES



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ARCHEOLOGICAL INVESTIGATIONS IN NEW MEXICO, COLORADO, AND UTAH

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INTRODUCTION

During the year 1916 the author spent five months in archeological investigations in New Mexico, Colorado, and Utah, three of these months being given to intensive work on the Mesa Verde National Park in Colorado. An account of the result of the Mesa Verde work will appear in the Smithsonian Annual Report for 1916, under the title "A Prehistoric Mesa Verde Pueblo and Its People." What was accomplished in June and October, 1916, before and after the work at the Mesa Verde, is here recorded.

As archeological work in the Southwest progresses, it becomes more and more evident that we can not solve the many problems it presents until we know more about the general distribution of ruins, and the characteristic forms peculiar to different geographical localities. Most of the results thus far accomplished are admirable, though limited to a few regions, while many extensive areas have as yet not been explored by the archeologist and the types of architecture peculiar to these unexplored areas remain unknown. Here we need a reconnoissance followed by intensive work to supplement what has already been done. The following pages contain an account of what might be called archeological scouting in New Mexico and Utah. While the matter here presented may not shed much light on general archeology, it is, nevertheless, a contribution to our knowledge of the prehistoric human inhabitants of our country. Primarily it treats of aboriginal architecture.

The author spent two months in searching for undescribed buildings concerning some of which comparatively nothing was known. During June, 1916, headquarters were made at Gallup, New Mexico: the Utah ruins, new to science, were visited from the Indian agency at Ouray, Utah.

The plan of operations in these two fields was somewhat different. The work in New Mexico was an attempt to verify existing legends

of the migrations of a Hopi (Walpi) clan that once lived in a ruined pueblo called Sikyatki, where the cemeteries, exhumed in 1895, yielded one of the most beautiful and instructive collections of prehistoric pottery ¹ ever brought to the U. S. National Museum from the Southwest.

Legends mention by name several habitations of the Sikyatki people during their migration from the Jemez region, before they built their Hopi pueblo, but lack of time prevented the author from tracing their trail throughout the entire distance back to their original home. The object of the present investigation was to examine one of their halting places, a ruined pueblo called Tebungki, or Fire House,² on the prehistoric trail about 25 miles east of Walpi. Between this ruined village and the ancestral home there are large and as yet undescribed ruins, such as those of the Chaco Canyon, which may once have been inhabited by some of these people.

Our knowledge of the former shifting of ancient clans, derived from legends, is fragmentary, and one way to gain further information and revivify forgotten or unrecorded history, is to study the remains of their material culture. Architecture is a most important survival, and pottery, which has transmitted ancient symbolism unchanged, is also valuable. It happens that both these aids characterize the southwestern culture areas. Other objects, as stone implements, woven and plaited fabrics, and basketry, are not greatly unlike those made by unrelated Indians and consequently add little to our knowledge in studies of cultures, but architecture and ceramics are distinctive and afford data from which we can gather much information on the history of vanished races.

TEBUNGKI (FIRE HOUSE)

Hopi legends of clans whose ancestors once peopled the Sikyatki ruin, but are now absorbed in the Walpi population, recount that in their western migration they built, near a deep canyon, a village which they named Fire House. These legends were first obtained from the Hopi by A. M. Stephen and recorded by Victor Mindeleff ³ who located Fire House ruin over 20 years ago. His valuable description and ground plan, the only account heretofore printed, is graphic and substantially correct. He calls attention to the charac-

¹ 17th Ann. Rep. Bur. Amer. Ethnology, Part 2.

² Called by the Navaho, Beshbito, Piped Water; from a metallic pipe at the spring.

³ 8th Ann. Rep. Bur. Amer. Ethnology, 1886-'87 (1901).

teristic or salient points which distinguish Fire House from ruined buildings in the Hopi reservation, especially its circular or oval form and the massive, well-constructed masonry of its walls.

The exact dimensions of Fire House (pl. 1) can be obtained only by excavation, but it is approximately 94 by 79 feet in greater and lesser diameter. Some parts of the outside wall are now 10 feet high, and its thickness averages 3 feet, but if the stones accumulated about

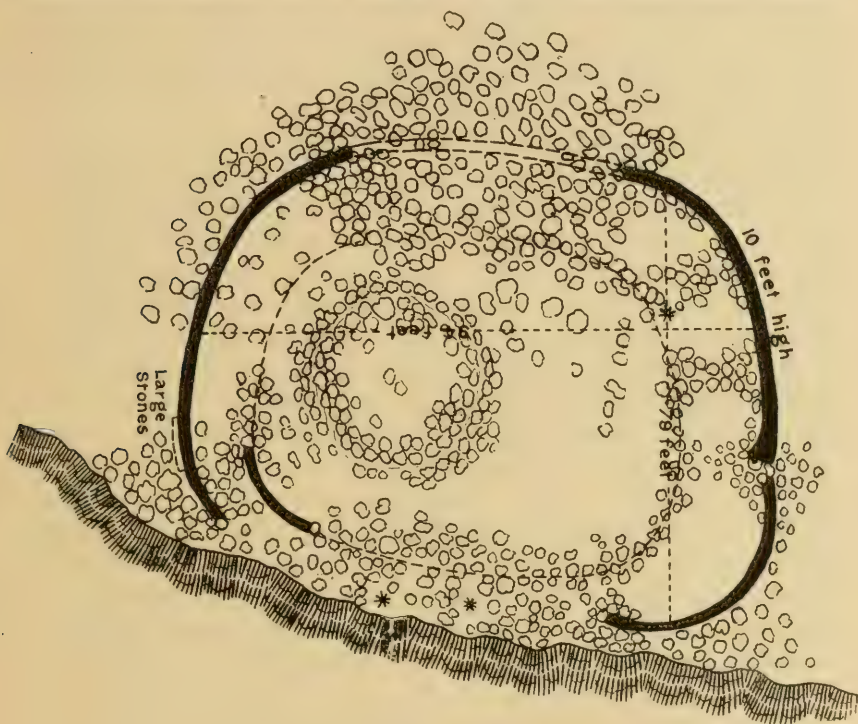


FIG. 1.—Fire House.

its base were removed the height would be 4 or 5 feet greater. There are evidences of an external passage-way through the outer wall indicating a central court. Within the enclosure there are many indications of rooms some of which appear to be circular, but the interior is so filled with fallen walls that an accurate ground plan could not be drawn without extensive excavation. The stones forming the wall are, as a rule, cubical blocks, well dressed and accurately fitted, showing good masonry.

Two of the largest of the wall stones are 5 feet long and 3 feet wide, with an estimated thickness of 2 feet. As it would take

several men to carry one of these stones from the quarry to its place in the wall, they might be called megaliths.

The fine spring at the base of the cliff below Fire House was evidently used by the inhabitants for drinking water, and the trail from here to a gateway in the outer wall is still well marked. As one climbs from the spring to the top of the plateau the way passes between the cliff and a flat stone set on edge and pierced with a hole about 5 feet above the pathway. This stone was evidently a means of defense; behind it the warriors may have stood peering down upon their enemies through this orifice. Near it are pictographs of unknown meaning.

The circular form of Fire House (fig. 1) and its well-constructed surrounding wall are more characteristic of eastern than of western pueblo masonry. This round type¹ is found from southern Colorado on the north to the neighborhood of the Zuñi settlements on the south; it has not been reported from the region on both banks of the Rio Grande. Roughly speaking, circular ruins correspond, in their distribution, with a line extending north-south midway between the eastern and western sections of the pueblo area—a limitation that can hardly be regarded as fortuitous. Its meaning we may not be able to correctly interpret, but the fact calls for an explanation. The type is old, the modern pueblos having abandoned this form. The area where circular ruins occur corresponds, in a way, to that inhabited in part by the modern Keres, none of whom, however, now dwell in circular towns. Provisionally we shall consider the Keresan pueblos as the nearest of all descendants of those who once inhabited villages of circular or oval form, a generalization substantiated by the existence of words of Keres language in many old ceremonies among all the pueblos.

There is a sharp line of demarcation between the zone of circular ruins and that inhabited by the pueblos along the Rio Grande, but on the western border these circular buildings extend as far west as the Hopi country.

In attempting to connect the oval form of Fire House with the rectangular form of Sikyatki we are met with the difficulty of architectural dissimilarity. Fire House is circular, Sikyatki is rectangular. If the descendants of the inhabitants of Fire House later

¹ An able discussion of the pueblo problems is found in the excellent compilation of Fritz Krause, *Die Pueblo-Indianer, Eine historisch-ethnographische Studie*. Nova Acta Kaiserl. Leop. Carol. Deutschen Akademie der Naturforschern. Vol. 87, No. 1, 1907.

constructed Sikyatki, why did they make this radical change in the form of their dwellings? They may have constructed a habitation en route before they reached Sikyatki, and this village may have had a form like Fire House. On the Hopi plateau above Sikyatki there are two conical mounds visible for a long distance as one approaches East Mesa from the mouth of Keam's Canyon, which should be considered in this connection. These mounds, called Kükütcomo, are connected in Hopi legends with those of Sikyatki at the foot of the mesa on which they stand, and the buildings they cover are said once to have been inhabited by the Coyote (Fire ?) clan of eastern kinship. They have not been excavated completely but several rooms have been opened up enough to show that they are round towers or kivas with rooms annexed to their bases. They resemble, in fact, circular ruins and may well have been the home of some of the people who abandoned Fire House. They must be considered in discussing the reliability of the legend, for they are the only circular houses yet reported from the Hopi country. The reason why this form of house was abandoned can not be determined with any certainty, even though some of the clans from Fire House may have built the round towers above Sikyatki. The only other round room known to me in the Hopi country, besides Kükütcomo, is one in a ruin in the Oraibi Valley mentioned by Victor Mindeleff (*op. cit.*). The reference is very meager and on account of its exceptional character should be verified. Assuming the observation as correct it may be said that this so-called circular room lies embedded in a mass of rectangular rooms and not as kivas in the inhabited Hopi pueblos in the plazas free from houses.

The legends of the Snake people of Walpi who came from the San Juan near Navaho Mountain, probably Betatakin or Kitsiel, distinctly state that their ancestors built both round and square or "five-cornered" houses. The rooms referred to are believed to be kivas, since another legend declares the earliest snake ceremonies were performed in circular rooms. After visiting Fire House the author desired greatly to find other oval ruins between it and the zone of circular ruins, but his efforts were not successful.

SEARCH FOR HOPI RUINS EAST OF TEBUNGKI

After having visited Fire House and verified to his satisfaction that it was a former home of a Hopi clan, as recounted in legends of that clan, the author sought still further evidence of an archeological character in the region east of Fire House, as recorded in migration stories. The area between Fire House and Jemez is exten-

sive and rich in ruins of all kinds, open air pueblos predominating. It is too great a task to visit all of these ruins during one summer, and the work accomplished in a single month seems small, but a beginning was made in the hope that the cumulative work of many summers will make it important.

The farther we recede from the Hopi country the more obscure become their clan trails, and the more difficult it is to identify the localities mentioned in legends. The inhabitants of some of the pueblos now in ruins between Jemez and Hopi, may have died out without leaving any representatives; others, when they left their village, may have gone to Zuñi or elsewhere. In the country east of Fire House, as far as Fort Defiance, several ruins were observed, but none of them seemed to show close archeological likeness to the oval Fire House, or to corroborate the traditions of the descendants of the clans now absorbed into the population of Walpi. A large ruin near Ganado was visited, and an imperfect sketch made of its ground plan. Its walls are so much worn down by the encroachment of the stream on one side, and the road on the other, that little could be learned from superficial examination. Although it is not a circular ruin like Fire House, yet an extended excavation might reveal some interesting details of ceramic symbolism¹ which would be important.

RUINS IN NASHLINI CANYON

Two cliff houses of small size were visited in Nashlini Canyon which appear to be those casually mentioned by Dr. Prudden,² but, so far as known, they have not been described. This canyon is one of the southern branches of the Chelly Canyon, and although not very extensive shares with it many characteristics. A trip can be made into it by automobile as far as the first cliff house.

The ruin most easily visited (fig. 2) in this canyon is on a comparatively low shelf in a shallow cave, 40 feet high, a few feet above the top of the talus. Like many other cliff houses it is divided into two parts, called the upper and the lower, according to the level they occupy. The lower is practically buried under rocks fallen from the walls of the upper house. The front wall of the upper part

¹ The specialized symbolism so elaborately shown on Sikyatki pottery is regarded as a local development and for that reason can not be expected elsewhere even in the ancestral homes of the clans whose later members lived at Hopi.

² The Prehistoric Ruins of the San Juan Watershed in Utah, Arizona, Colorado and New Mexico. *Amer. Anthropologist*, N. S. Vol. 5, p. 280.

is well preserved and closely follows the contour of the low ridge on which it stands. The masonry is fairly good, but the floors of the rooms are buried under a thick deposit of sheep droppings, solidly packed, showing that the enclosures have been used secondarily as corrals for these domesticated animals. The partition walls of the rooms end on the vertical wall of the precipice, the face of the precipice serving as their rear wall. It thus happens that there is no recess between the back of the rooms and the rear of the cave, as commonly found in cliff dwellings. Circular rooms are absent in the upper part of this ruin, and kivas, if any, must be sought buried

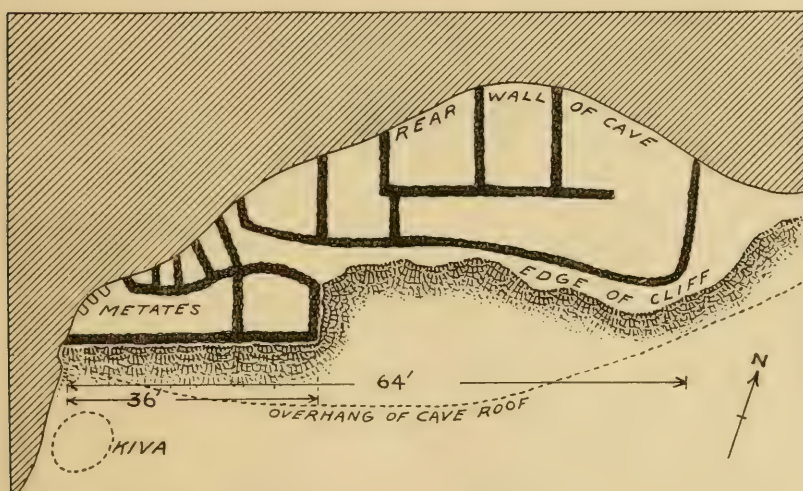


FIG. 2.—Ground plan of cliff ruin in Nashlini Canyon.

under the accumulated débris of the lower part. The front wall of the upper house measures 64 feet, and can be traced throughout its whole extent. At one end of the ruin there are four narrow rooms separated by partitions, each containing a grinding bin, where maize (corn) was reduced to meal. The remaining rooms are roofless, plastered, and evidently used as dwellings. In the lower series of rooms, buried beneath a mass of fallen rocks, are circular depressions, which may be ceremonial rooms; but no excavations were made in these depressions and their significance is unknown.

Another cliff house, a few miles farther up in the canyon, is almost hidden in an inaccessible recess of the cliff, but so high that it was not visited.

On the dizzy top of a cliff overlooking the canyon, near the second ruin, artificial walls were observed but not visited. An Indian guide claimed that they were towers; they are certainly so situated as to permit a wide view up and down the canyon. These walls are mentioned by Dr. Prudden.

On the walls of the canyon not far from the first ruin there is an instructive group of pictographs (fig. 3) representing human beings, some painted red, others white, standing in three lines. The majority have triangular bodies with shoulders prolonged into arms at right angles to the body; the forearms hanging from their extremities, as is common in this region. On each side of the head are lateral exten-



FIG. 3.—Pictographs near mouth of Nashlini Canyon.

sions recalling the whorls in which Hopi maidens still dress their hair, a custom that has passed out of use among the other pueblos, but is still preserved in personifying supernatural beings called Katsina maids. It appears to have been a universal custom of the unmarried women among the cliff dwellers to dress their hair in this fashion. These figures are arranged in three rows; three individuals are depicted in the upper row, four in the middle, and two in the lower row painted white, unlike the others. Below the figures are rows of dots and several parallel bars accompanied by a number of zigzag figures like lightning symbols. On the supposition that the red figures represent Indian men or women, the white figures may be white men and the dots and bars an aboriginal count, the whole representing participants in some past event.

CHIN LEE CLIFF HOUSES

Along southern tributaries of Chin Lee Valley there are instructive cliff houses that have escaped the attention of archeologists. Judging from his map, some of these may have been visited by Dr. Prudden for he gives a figure of one of the two cliff ruins (pl. 2, fig. *a*), in the Chin Lee, about 40 miles from Chin Lee postoffice. Their state of preservation and the character of their sites may be judged from the accompanying illustrations. These ruins were not visited, the photographs (pl. 2, figs. *a-c*) having been presented by a Navaho Indian, George H. Hoater, who made the pictures but did not know the name of the ruin or of the canyon. There are other ruins in the Chin Lee canyons, of which information is quite meager.

RUINS NEAR GALLUP, NEW MEXICO

The geographical position of the country about Gallup renders it a very important area in the study of the migration of aboriginal peoples in the Southwest. It lies midway between the Rio Grande on the east and the Little Colorado on the west, and between the San Juan on the north and the Zuñi on the south. In their intercommunication, the trails of migration in prehistoric times must have crossed this region, and as this migration was marked by successive stages where buildings were constructed we should expect here to find remains of former migratory peoples. Ruins in the vicinity of Gallup have been so much neglected by students that our knowledge of this region is very fragmentary. To remedy this condition the author made a few trips in this vicinity with Mr. Sanderson and Mr. Bruce Draper, local students, who furnished important aid. A number of pueblo sites and small cliff houses within a few miles of the city were visited and superficially examined, but no intensive work was done upon them. The ruins mentioned below are only a few of those in this region that could be brought to light by systematic scientific exploration. From his examination of them, it is the author's impression that the majority were inhabited by ancestors of clans now domiciled in Zuñi.

ZUÑI HILL RUINS

This extensive ruin (pl. 3, *a, c*), 6 miles south from Zuñi station on the Santa Fe railroad, and about 11 miles from Gallup, lies almost directly opposite a conspicuous pinnacle of Wingate sandstone called the Navaho Church. Its site is a low ridge extending north and south for several hundred yards. None of the walls rise above the mounds

which are highest on the west side. There are numerous depressions scattered among the mounds which suggest subterranean rooms of circular form. A round depression 40 feet in diameter shows the remnant of a wall on one side. On a "flat" north of the ruin several piles of stone can be seen, which are interpreted as isolated houses; near one of them is a small fireplace made of slabs of rock set on edge surrounding an enclosure filled with ashes. This is without exception the largest cluster of mounds in the immediate neighborhood of Gallup, and would well repay excavation and further study.

KIT CARSON GROUP

This group of mounds has received its name from Kit Carson Spring which lies in their neighborhood. It is situated north of Navaho Church on an elevation overlooking the road from Gallup to Crown Point. The members of the group are numerous, but each mound is comparatively small. In no case were walls found rising above the mounds, but as nearly as could be judged from their shape, the buildings covered had rectangular outlines and were accompanied by circular depressions. Fifty feet south of the largest mound of this group there is a semicircular pile of rocks which measures 42 feet on the south side, and with a radius of 30 feet from this side to the curved wall. The main ruin has lateral extensions on the north and south ends, and measures 70 feet by 41 feet. The lateral extensions give the mounds the shape of the letter **E** and enclose a square room of rectangular form measuring 20 by 15 feet.

RUINS IN HEMLOCK CANYON

Hemlock Canyon, north of the road from Gallup to Crown Point, has the general features of other canyons in this neighborhood. At its mouth there are fertile fields, and a good spring which a Navaho has appropriated by building a hogan and fencing off the entrance. About a half mile from this spring following the right bank of the arroya, which rarely contains water, there is a house (pl. 11, *a*) built in a recess of the cliff about 10 feet above small scrub trees which here grow in abundance. Its foundation is about 6 feet long, and the wall is slightly curved and well constructed, showing a doorway shaped like the letter **T**. This house is not regarded as a dwelling, for it is too small for a family, and no household implements have been found within the enclosure. It belongs rather to a type of cave-house called "ledge rooms," many examples of which occur

near larger dwellings. It was probably a storeroom, although possibly a retreat where priests retired to pray for rain, as was once the custom among the Hopi. The people to whom this house belonged probably dwelt near their farms a short distance from the base of the cliff. There is a similar room known to have been constructed by Navahos a few feet off the road from Gallup to Crown Point, which is still used for a granary, indicating the probable use of the small building here described.

RUINS NEAR BLACK DIAMOND RANCH

Black Diamond Ranch is 13 miles north of Hosta Butte. Mr. Bruce Draper, who owns the ranch, pointed out near the mouth of a neigh-

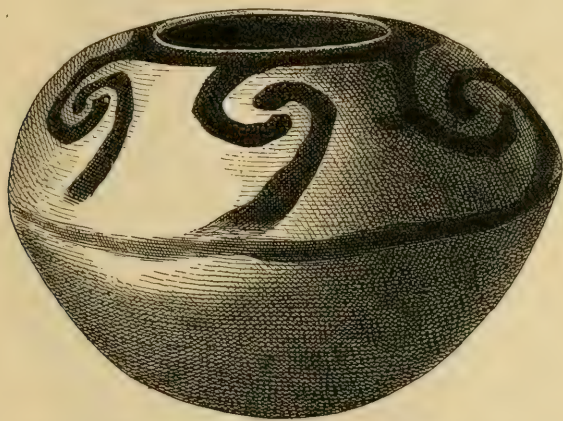


FIG. 4.—Spherical bowl, Black Diamond Ranch. $7\frac{3}{8}$ by 5 inches.

boring canyon several comparatively large ruins. In one of the largest of these (pl. 3, *b*) near the ranch house, no walls are visible above ground, but the surface presents abundant evidence of a buried ruin. In one corner of this ruin (pl. 3, *b*) Mr. Bruce dug out a small room which has good plastered walls, several feet high, and found decorative bowls, some of which are here figured (figs. 4, 5). About 50 feet south of this ruin, a low mound suggests a cemetery, and about the same distance still farther south, a depression on the surface indicates a circular subterranean room or reservoir.

Following up this canyon nearly to its head, there is a small ruin hardly worth mentioning save for a spiral incised pictograph 3 feet in diameter identical with the snake symbols widely distributed throughout the Southwest.

In all the region north of the high ridge of eroded Wingate sandstone there are several other groups of ruins with most of the walls very much broken down. It would probably be conservative to state that there were over 200 ruins, large and small, in this region, showing evidence of a considerable population, if they were inhabited simultaneously. Fragments of pottery occur on almost every ridge overlooking the trails, especially along the road from Gallup to Crown

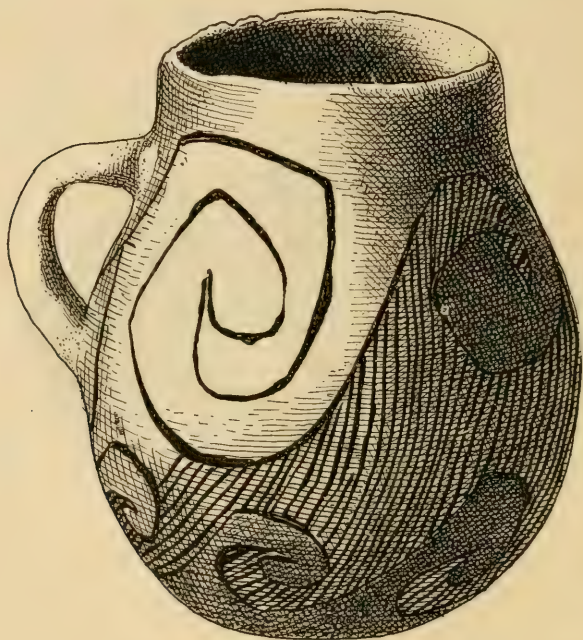


FIG. 5.—Mug with decoration half completed. $5\frac{1}{2}$ by $4\frac{1}{2}$ inches.

Point. The forms of these ruins vary and can be made out only by systematic excavation.

So far as limited exploration about Gallup has gone, the investigations by the author show that the ruins were inhabited by Zuni clans, as indicated in the structure of the buildings and the symbols on the pottery. It would be important to determine the relative age of these ruins compared with those about Zuni; as to whether they were peopled by colonies from Zuni, or whether their inhabitants joined the Zuni population after deserting these houses. Although there is not sufficient evidence to prove the latter proposition, the author is inclined to accept it.

CROWN POINT RUINS

No more interesting question in southwestern archeology awaits an answer than the query: What became of the former inhabitants of the Chaco ruins, one of the largest clusters of deserted buildings in New Mexico? Like the cliff dwellers of the Mesa Verde, their former inhabitants have disappeared and left no clue as to where they went, the date of their occupation of the ruins, or their kinship with other peoples. Existing legends relating to them among supposed descendants who are thought to live in modern pueblos are fragmentary and knowledge of their archeology is defective. The Hyde Expedition made an extraordinary collection of artifacts from Pueblo Bonito, the largest and formerly the best preserved ruin of the group, but the excavations there have yielded little information on the kinship of its inhabitants. Until we know more about the Chaco Canyon ruins we are justified in the belief that there still remains a most important problem for the archeologist to solve.

In seeking the prehistoric migration trail of the Hopi before they came to Fire House, the author examined ruins near Crown Point identical with those of the Chaco Canyon. There are in fact two ruins within a few miles of the Crown Point Indian school, one of them known among the Navaho Indians as Kin-a-a (the name of the other unknown to the author), which are structurally members of the Chaco series.

The ground plan of the largest, Kin-a-a,¹ is rectangular and was apparently oriented north and south, the walls on the north side being the highest and best preserved and those on the south possibly terraced. On the south side remnants of a court or enclosure surrounded by a low wall can still be detected. The ruin is compact with embedded kivas and measures approximately 150 feet long by 100 feet wide, the north walls rising in places to 50 feet, showing good evidences of five stories, one above the other. The high walls reveal rooms of rectangular shape. Situated midway in the length of the north wall (pl. 4, *a*, *b*, *c*) is a circular chamber like a kiva on the ground floor, with high walls about it. The recesses between the wall of the circular room and the rectangular wall enclosing it are solidly filled in with masonry, a mode of construction adopted in the great ruins of the Chaco Canyon. The kiva of Kin-a-a (pl. 5, *a*, *b*),

¹ This ruin has been added to the National Monument known as the Chaco group.

The name Kin-a-a seems to have been applied by the Navaho to at least two ruins. This particular Kin-a-a is possibly the ruin described by Chas. F. Lummis to which Bandelier refers.

like those of the great building of the same canyon, are built into the mass of rooms and not separated from them as in the modern pueblos, Walpi, those of the Rio Grande, and the ruin of Sun Temple on the Mesa Verde. This separation of the kiva from the house mesa is regarded by the author as a late evolution, being unknown among the cliff dwellers, and very rare in pueblo ruins possessing ancient characteristics. A union or huddling together of sacred and secular rooms is characteristic of the period when each kiva was limited to the performance of clan rites, the separation of the kiva from secular rooms marking the development of a fraternity of priests composed of different clans. The diameter of the kiva in Kin-a-a is about 15 feet, the average size of these rooms, no doubt determined by the length of logs available for roofs. When the diameter is greater than that it is customary to make the roof in a vaulted form by utilizing shorter roofing, but kivas as small as 10 feet in diameter were sometimes roofed by vaulting. Depressions, in mounds, measuring as much as 50 feet in diameter, in ruins in the Montezuma Valley have been identified as circular ceremonial rooms, but as these have not been excavated, there is always a doubt, for instead of being ceremonial and roofed they may have been uncovered reservoirs for storage of water, for not all circular depressions are kivas. In Far View Pueblo,¹ in the Mummy Lake Group, the author excavated a kiva 32 feet in diameter, which was found to have pilasters for a vaulted roof. No such pilasters occur in Kin-a-a, showing that the roof was flat with a central hatchway, as is customary in all these rooms with two or more stories.

It is difficult to explain the enclosed space above the kiva in this ruin. Was it occupied by rooms one above another, or was the lower open to the sky? The rows of holes interpreted as indicating floors is without significance, unless there were a number of superposed rooms. It must be remembered that the ceremonial room or kiva, in modern mythology, represents the underworld out of which, according to legends, the early races of men emerged through an opening in the roof or hatchway. Among the Hopi it is never covered by another room, and this is carried so far that it is forbidden to walk on a roof of a kiva, especially at a time when rites are being performed.² Such an act would be regarded as sacrilegious,

¹A Prehistoric Mesa Verde Pueblo and its People, Smithsonian Report for 1916.

²At certain times in Hopi ceremonies a thin layer of sand is sprinkled over the kiva roof, and on this sand are drawn in meal four rain-cloud figures, around which are performed certain secret rites.

and the same taboo is now probably universal: consequently walls constructed 40 feet above the top of the kiva, showing evidence of rooms superposed in stories, are exceptional. The object of rooms above a kiva can only be surmised; possibly there may have been four kivas, one above another, to represent the underworlds in which the ancestors of the human race lived in succession before emerging into that in which we now dwell. The inner walls of this kiva are shown in plate 5, *a*. It was evident to the author when examining the inner wall of the superposed room, above that identified as the kiva, that it belonged to a room with a roof, as appears also from the view here given (pl. 5, *a*). Whatever explanation of this exceptional condition may be suggested, we cannot question the fact that here we have remains of a kiva below one or more other rooms.¹

A well blazed trail passes the ruin and is lost in the distant hills. This trail was at first mistaken for an irrigation ditch, but an examination of its course shows that it runs up a steep hill, which precludes such a theory. It is a section of an old Indian trail, indications of which occur elsewhere in the State, a pathway over which the rocks used in the construction of the ruins were transported. A similar trail used for a like purpose is recorded near the great ruin at Aztec, New Mexico.

RUIN B NEAR CROWN POINT

Ruin B (pl. 6, *a*, *b*), largely made up of a kiva of circular form within a rectangular enclosure, lies near Crown Point on top of a low plateau, back from the edge. Its name is unknown to the author, but from its size and the character of its masonry it must formerly have been of considerable importance. It was not, like Kin-a-a, included in the President's proclamation making the Chaco Canyon ruins a National Monument. The appearance of the masonry and the structure of the circular room, identified as a kiva, leads the author to place it in the same class as the Chaco ruins, its nearest neighbor being Kin-a-a, east of Crown Point. The excavation of this ruin might shed instructive light on the extension or migration of the inhabitants of the Chaco, after they left their homes in that canyon.

A ground plan of this ruin (fig. 6) shows that the standing walls are rectangular and practically surround a circular room or kiva.

¹ A two or three storied kiva like that of the Crown Point ruin is mentioned by Jackson in his description of Chettro Kettle ruin of the Chaco group, and is one of those features possibly existing in the tower kivas which are now extinct.

The walls are double, the interval between the inner wall and that of the circular chamber being filled in with solid masonry.¹ The outer of the two enclosing rectangular walls is separated from the inner by an interval of about 7 feet, and is connected with it by thin partitions, somewhat analogous to those described as connecting the two concentric walls² of circular towers on the McElmo.

No other walls were observed above ground in this ruin, although small piles of stone were noticed which may have been walls of other

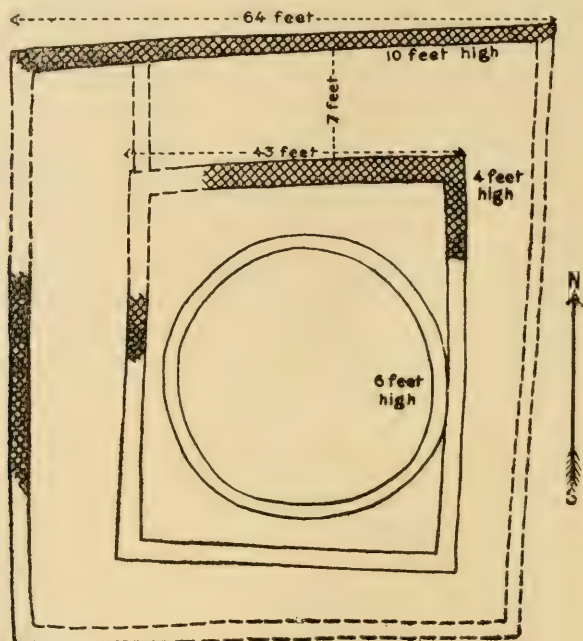


FIG. 6.—Ground plan of ruined kiva near Crown Point.

buildings. The reason why the walls about the kiva have been preserved so much longer than those of neighboring secular cham-

¹ Although the author has observed several towers with fallen rock about their bases, he has not been able to trace three concentric walls with connecting partitions.

² The circular kivas of the two ruins near Crown Point are enclosed by four standing walls forming sides of a rectangle, a feature they share with some of these chambers in the Chaco and San Juan region. The intention of the builders was to secure the prescribed subterranean feature by construction of a rectangular building about the circular room rather than by depression below the level of the site. This type is now extinct, but belongs to the most advanced stage of pueblo architecture before its decline.

bers, is probably because of the universal care exercised by man in the construction of the walls of religious buildings.

POTTERY

Brief mention of ceramic objects found in the area considered in this review is here introduced because they substantiate the evidences of the buildings concerning the relationship of prehistoric people in



FIG. 7.—Decorated handled cup, Black Diamond Ranch. $5\frac{1}{2}$ by 4 inches.

this neighborhood. Moreover, they add to our limited knowledge of the arts in a little-known area. Very little has been recorded concerning pottery from the ruins near Gallup, but the few known specimens do not bear a sufficiently specialized symbolism to separate them from others found in different geographical areas. Evidently no distinctive ceramic area was developed in this region. Attention, however, may be called to the fact that the symbols on pottery (fig. 7) represent the oldest types, and that geometrical designs rather than conventional animal figures predominate. The pottery

suggests Zuñi ware, but is radically different from modern Zuñi and has different symbols, showing, as far as it goes, that settlements in which it occurs were made prior to the development of modern Zuñi ceramic decorations which were influenced by them. It has a likeness to old Zuñi ware, but has a closer resemblance to fragments from the Crown Point Ruin, and the Chaco settlements, which is significant.

Perhaps the most exceptional specimens obtained during the author's trip are two large, black jars (fig. 8), their color recalling

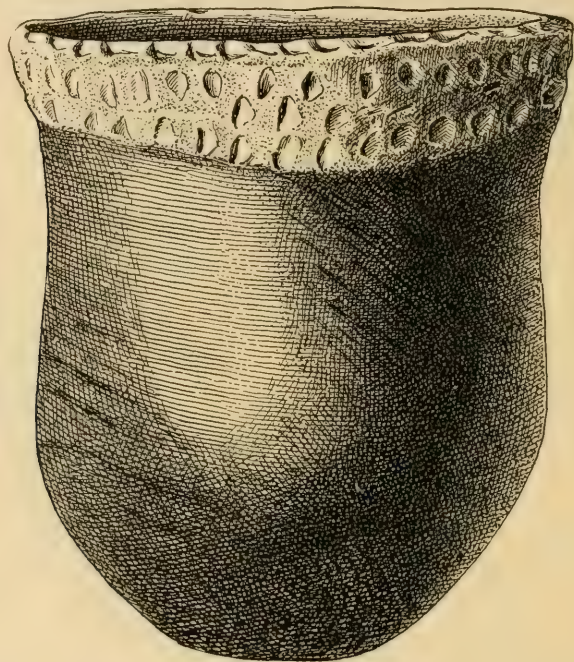


FIG. 8.—Cooking pot, Black Diamond Ranch. $7\frac{1}{2}$ by 6 inches.

Santa Clara ware. The decoration on these jars takes the form of designs on a raised zigzag band meandering about their necks, similar to pottery used by the Navaho Indians. The informant, a reliable white man, claims they are not Navaho work, and showed the locality near a ruined ancient wall where he excavated them. He also reports a portion of a human skeleton found in the same neighborhood which affords good indication that they were mortuary, while the position of the grave would show that they were deposited by the same people who inhabited the room near by. The question is pertinent, however,

whether they were not a modern secondary burial; but if we accept this theory it indicates an unusual condition, for the Navaho seldom bury their pottery as mortuary offerings.¹

The author noticed, especially in his examination of the mounds near Kit Carson Spring, certain foundation walls indicating small, circular, buildings strung along in a row on the tops of ridges. One or two of these suggest a round ruin near Zuñi, and seem to afford the missing link in the prehistoric chain of settlements connecting the great Chaco ruins² with some of those in Zuñi valley. These important similarities are supported by the traditions of the Zuñi that some of their ancestors once inhabited the buildings on the Chaco; and the fact that certain ruins, among them Kintiel, north of Navaho

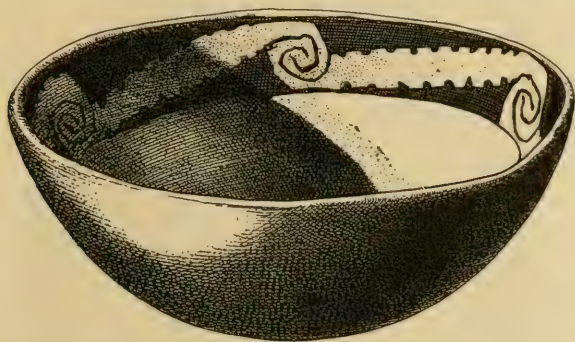


FIG. 9.—Decorative food bowl, Black Diamond Ranch. 7 by 3 inches.

Springs, are definitely claimed by the Zuñi to have been inhabited by their Corn clan.

The black and white pottery, found about Gallup, is identical with that of the latter ruin, and very similar to that generally found in the earliest epoch of pueblo occupancy. As pointed out in an article on Zuñi pottery, in the "Putnam Anniversary Volume," modern Zuñi pottery is so different from the ancient that we can hardly regard it as evolved from it. The same is true among the Hopi; the modern pottery decoration is not like the old, but is Tewa. Hopi-Tewa pottery is largely the work of Nampeo, who once decorated her pottery solely with Tewa symbols instead of old Hopi. In 1895

¹ The Navaho are not a pottery making people, but often use bowls and vases they find in prehistoric ruins.

² Although prehistoric, the author regards all the Chaco Canyon group of ruins as later in construction than those of the Mesa Verde and San Juan, with which they are morphologically connected.

she abandoned the Tewa symbols of her people to meet a demand for old pottery and substituted for Tewa designs copies of ancient Hopi pottery from Sikyatki. Thus there have been two radical changes in the style of Hopi pottery since 1710; one the substitution of Tewa designs for old Hopi, the other a return to Sikyatki motifs within the last 20 years. This modern innovation, however, has not been derived from the ancient by any evolution, but by acculturation. Possibly a similar change has taken place at Zuñi, calling for caution

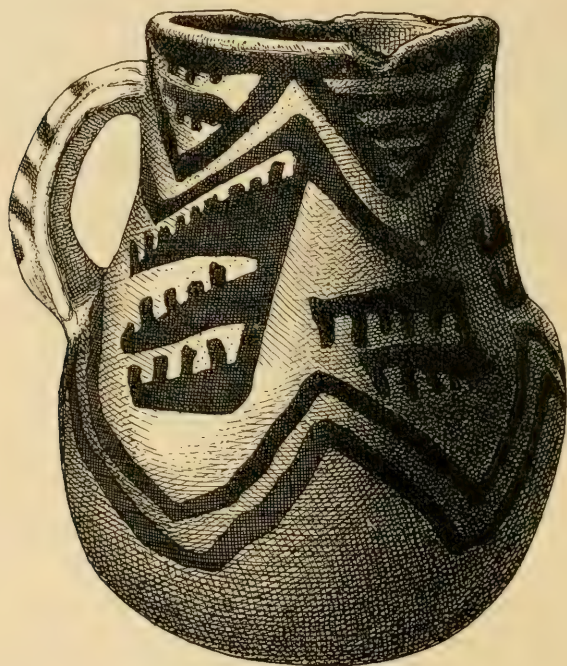


FIG. 10.—Decorated handled cup, Black Diamond Ranch. $6\frac{3}{8}$ by $5\frac{1}{4}$ inches.

in supposing that pottery found in the refuse heaps is necessarily evolved from that preexisting or found in strata below it.

The author has seen no evidence that would lead him to abandon the theory, that the Zuñi valley was once peopled by clans related to those on Little Colorado derived from the Gila, and that other clans drifted into the valley from the north at a later date. These later additions were from the circular ruin belt. Later came Tewa clans as the Asa of the Hopi, and others. The author finds more evidences of acculturation than autochthonous evolution in modern Zuñi, as in modern Hopi ceramic symbols. Pottery (figs. 9, 10) found in ruins

about Gallup belongs to the same type as that from Kintiel which Cushing, from legendary evidences, found to have been settled by Zuni clans.¹

RUINS IN HILL CANYON

The country directly south of Ouray, Utah, is an unknown land to the archeologist. Geologically speaking it is a very rugged region, composed of eroded cliffs and deep canyons which up to within a few years has been so difficult of access that white men have rarely ventured into it. At present the country is beginning to be settled and there are a few farms where the canyon broadens enough to afford sufficient arable land for the needs of agriculture. The canyon is very picturesque, the cliffs on either side rising from its narrow bed by succession of natural steps (pl. 7, *a*) formed of sandstone outcrops alternating with soft, easily eroded cretaceous rock. Its many lateral contributing canyons are of small size, but extend deep into the mountain in the recesses of which are said to be hidden many isolated cave shelters, and other prehistoric remains. The cliffs and canyons of this region are not unlike those farther south along the Green and the Grand Rivers, a description of which, quoted from Prof. Newberry,² pictures vividly the appearance of the weird scenery in these canyons. He says :

From this point the view swept westward over a wide extent of country in its general aspect a plane, but everywhere deeply cut by a tangled maze of canyons and thickly set with towers, castles, and spires of varied and striking forms; the most wonderful monuments of erosion which our eyes already experienced in objects of this kind had beheld. Near the mesa we are leaving stand detached portions of it of every possible form from broad, flat tables, to slender cones, crowned with pinnacles of the massive sandstone which forms the perpendicular faces of the walls of the Colorado. These castellated groups are from 1,000 to 5,000 feet in height, and no language is adequate to convey a just idea of the strange and impressive scenery formed by their grand and varied outlines. Their appearance was so strange and beautiful as to call out exclamations of delight from our party.

In this wild country up to his time rarely visited by white men, Prof. Newberry also graphically described ruins not greatly unlike some of those in Hill Canyon as follows:

Some two miles below the head of Labyrinth Canyon we came upon the ruins of a large number of houses of stone. Evidently built by the Pueblo

¹ 4th Ann. Rep. of the Director of the Bur. Amer. Ethnol.; also 22d Ann. Rep. Bur. Amer. Ethnol., pp. 124, 125.

² This account is taken from a report of an Exploring Expedition from Santa Fé, New Mexico, in 1859, under command of Capt. Macomb; published in 1876 by the Engineers Department, U. S. A.

Indians as they are similar to those on the Dolores, and the pottery scattered about is identical with that before found in so many places. It is very old but of excellent quality made of red clay coated with white and handsomely figured. Here the houses are built in sides of the cliffs. A mile or two below we saw others crowning the inaccessible summits, inaccessible except by ladders, of picturesque detached buttes of red sandstone, which rise to the height of 150 feet above the bottom of the canyon. Similar buildings were found lower down and broken pottery was picked up upon the summits of the cliffs overhanging Grand River. Evidence that these dreadful canyons were once the homes of families belonging to that great people who formerly spread over all this region now so utterly sterile, solitary and desolate.

Prof. Montgomery,¹ in an article on the ruins in Nine Mile Canyon, gives a description of similar prehistoric remains which he had found in that region. From this description the author of the present paper supposes that these ruins belong to the same type or one very similar to those found in Hill Canyon. The antiquities Montgomery mentions are well preserved, for he speaks of one of the towers in this region as about 50 feet high, standing in an almost inaccessible spot commanding a magnificent view of several canyons and mountains. He says:

On the top of a mesa in an extremely dizzy situation, were the remains of three small stone circular structures, two of which were provided with roofs of heavy cedar logs and heavy, flat stones. The logs and poles of these two structures would make about a cord of wood, and they possessed distinct marks of the rude stone axes with which they had been cut into suitable lengths. * * * On the south side of the canyon, and about a mile from Brock's Postoffice, I explored a strong and well-built stone structure, which stood upon a high and precipitous cliff. It formed about the two-thirds of a circle, being 14 feet long, 12 feet wide, and 5½ feet high, and was completed by a cliff in its rear. * * * In a short time we came to the rock column, which, although hard and solid was much disintegrated and had been vertically cleft and separated, leaving a dangerous gap between its two inclined and overhanging portions. By the aid of cedar poles we succeeded in clambering to its summit, and there, in a situation that commanded a magnificent view of many canyons and hills, we found the ruin of four circular stone structures which, in my opinion had once been a look-out, and signal military station. They were arranged upon the flat top of the rock in such a manner that three smaller ones, each capable of holding but one man, occupied the front and most exposed places, one of them being in advance of the other two, which were nearer the sides of the rock. The fourth and largest stone structure held a place several yards in the rear of the three small ones, but from it a clear view of a wide and extended tract of country could also be obtained. They were all destitute of openings except at the top, and their walls sloped inward from below, so that the opening in each of the three small structures was small and only sufficient to allow the entrance or exit of one person.

¹ Prehistoric Man in Utah. The *Archæologist*, Nov., 1894, pp. 335-342.

The author's attention was called to ruins in Hill Canyon like those above mentioned, by Mr. A. H. Kneale, agent of the Utes at Fort Duchesne, Utah, and at the close of work at Mesa Verde a trip was made into the region where they are found. The route was from Grand Junction, Colorado, to Mack, Utah, by rail, thence by rail to the end of the road at Watson. The trip from Watson to Ouray was by automobile. At Ouray the author outfitted with wagon, forded the Duchesne River, and crossed the Green River by ferry. Later he proceeded south to Squaw Crossing on Willow Creek, and thence to Taylor's ranch, in the midst of the ruins of Hill Canyon.

The ruins mentioned below were visited, but many others were reported by cowboys which were not seen on account of limitation in time, the object of the visit being primarily a reconnoissance.

The following ruins were seen by the author and his companions during their short visit to this region:

1. Ruins *A* and *B*, on the canyon rim within sight of Taylor's lower ranch.
2. Two ruins on pinnacles of rocks $1\frac{1}{2}$ miles from Taylor's lower ranch following the canyon southward.
3. Tower ruin crowning a leaning pinnacle.
4. Ruin on top of a plateau with precipitous sides, in middle of a canyon 3 miles south of Taylor's lower ranch.
5. Walls on top of an inverted cone, 6 miles up the canyon from Taylor's lower ranch.
6. Several towers in a cluster on a point of the plateau 8 miles below Taylor's lower ranch.¹

The above ruins may be classified into two types distinguished by the character of their site: (a) True "mushroom rock ruins," as their name implies, are perched on tops of isolated rock pinnacles resembling the so-called Snake rock at Walpi, and (b) the second type, crown spurs of the mesa overlooking the canyon. The pinnacle foundations of the former are the last stage in erosion of a spur from the side of the canyon. It is doubtful whether these pinnacles were cut off by erosion before or after the buildings thereon were constructed. On the whole both types of ruins in Hill Canyon present no architectural differences from those found in some of the tributary canyons of the Colorado River.

The author's visit to the Hill Canyon region was mainly a reconnoissance to verify reports of the existence of prehistoric remains in this little-known region. He was accompanied by Mr. T. G. Lemmon of Dallas, Texas, a volunteer, who furnished the Hill

Canyon pictures here reproduced. Mr. Owen, the official farmer of the Ute reservation, and an Indian boy accompanied us, the former as guide, the latter as driver. In penetrating this secluded country we were obliged to camp along the way, but were hospitably received by the few ranchmen along the route and made our home for a few days at Taylor's lower ranch while making our excursions to the ruins. It is a great pleasure to acknowledge this aid and especially that of Mr. Kneale, who aided us in outfitting at Ouray.

The best preserved examples of characteristic Hill Canyon Ruins belong to the second type, or those not isolated from the neighboring plateau, the most striking of which belong to the mushroom type. Both have a general similarity in circular form and massive walls, recalling, except in poor quality of masonry the so-called "towers" of the McElmo Canyon. They resemble the "Tower ruin," found by Prof. Montgomery, in Nine Mile Canyon, on the western slope of the range. Their masonry is composed of natural slabs of rock, rudely fashioned by fracture, but rarely dressed in cubical blocks, as in the towers on the McElmo Canyon. Their exposure to the elements has led to considerable destruction, the adobe in which the walls were laid having been washed out of the joints. The lower courses of stone, as seen in the view of the large ruin perched high above the ranch house, were of larger stones than the upper, and showed more evidences of having been dressed than the flat stones piled one on the other, which form the upper courses.

RUINS NEAR TAYLOR'S LOWER RANCH

RUIN A

The two large buildings near Taylor's lower ranch, ruins A and B, are typical of the first group, the most conspicuous of which, ruin A, is shown in the accompanying figures (pl. 7, *b*, pl. 8, *a*). This ruin stands on the point of a high cliff, inaccessible except on the west side. Although the special features of the masonry are somewhat obscured by fallen sections, and the form (fig. 5) is hidden, it is a circular enclosure about 25 feet in diameter, its wall being about 13 feet high, at the highest point. Between this high outer wall (fig. 11) and that of the inner circle, there are remains of a banquette or bench, surrounding the chamber very much broken down. The lower stones are much larger than the upper, similar in this respect to the walls of certain cliff dwellings. The circular room and

bench once covered the point of the mesa, and is separated from the plateau by a deep fissure worn in the rock outside the wall on that side. The height of the highest wall is 20 feet, and the bench around the circular portion averages 3 feet high. In thickness the walls vary from 1 to 3 feet. On the second ledge, or outcrop of hard rock

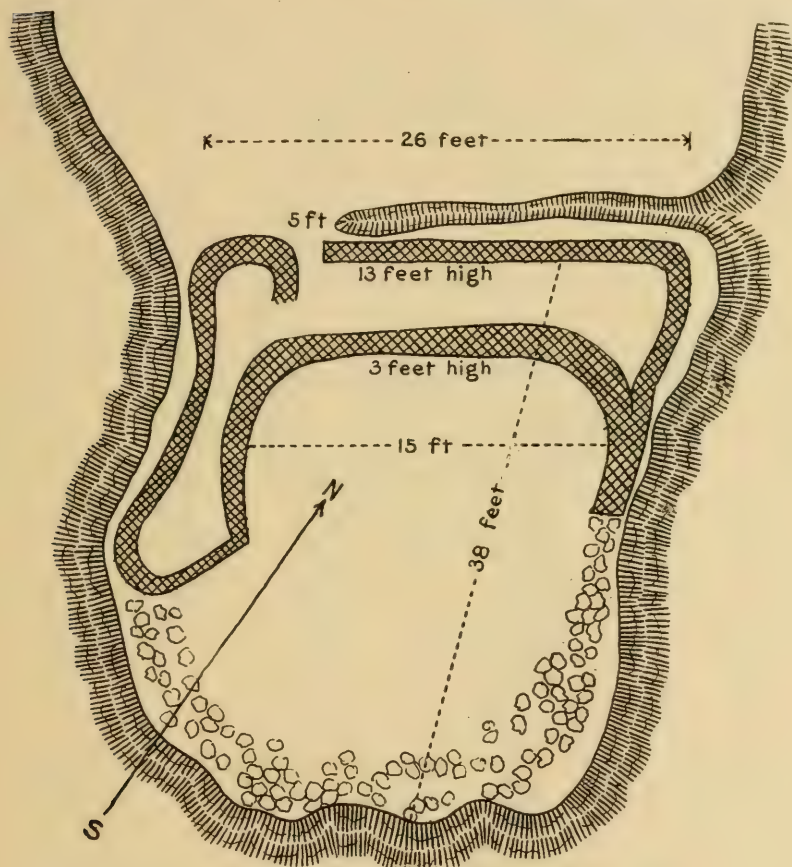


FIG. 11.—Ground plan of ruin A, Hill Canyon, Utah.

below the summit of the cliff, on which ruin A stands, there is a fine example of the dug-out type of habitation, several of which occur in the sides of this canyon. The roof of this type of dug-out is formed by a flat slab of rock projecting horizontally from the cliff and forming the protection for a chamber excavated in the soft rock below. In some instances these dugouts have rudely constructed lateral and front walls but none of them has more than one room. They appear

to have been inhabited rooms but may at times have served for shelter.¹

RUIN B

Ruin B (pls. 7, 8, *b*) is a better preserved example of the tower type and is on a ridge considerably lower than that on which ruin A stands extending at right angles. It occupies a narrow space from the rim of Hill Canyon on one side to a rim of a tributary canyon, blocking the passageway along the surface of the ridge to its point. This structure (fig. 12) would appear to be structurally not unlike ruin A, but with the wall smaller. There is a raised bench on the south side,

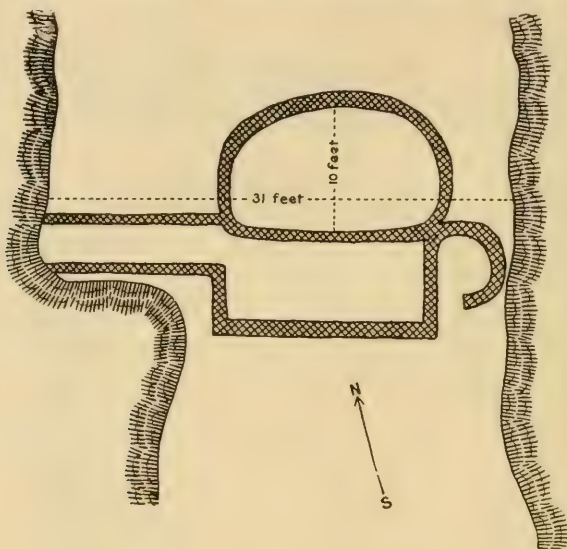


FIG. 12.—Ground plan of ruin B.

the tower itself being a semi-circular chamber annexed to the north side, which extends from one canyon rim to another. The breadth of this semi-circular room is 10 feet. The longest dimension is 31 feet and the average height of its wall is 4 feet. The top of the wall, throughout, is unevenly broken down, the part adjoining the bench being the best preserved. The structure suggests a fort, for it would not be possible to pass between this obstructing ruin without entering it through a circular doorway, the walls of which still stand on the east side. There is no passage between the wall and the mesa edge.

¹ We have in Hill Canyon ruins a good illustration of an all but universal custom, among prehistoric people, of dual types of rooms, one ceremonial, the other domiciliary, each constructed on different architectural lines.

LONG MESA RUIN

On the flat top of a long and narrow mesa (pl. 9, *a, b*) rising about 200 feet from the middle of Hill Creek Canyon a few miles above Taylor's ranch, there is a cluster of three circular ruins, whose walls are composed of well constructed masonry, now much dilapidated. The surface of this plateau, near the end looking down the

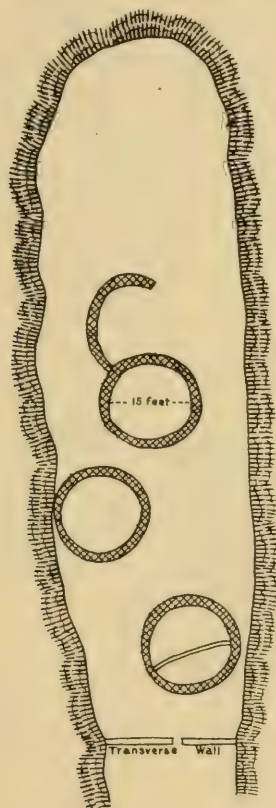


FIG. 13.—Ground plan of towers on Long Mesa.

canyon, is partitioned off from the remainder by a low transverse wall, extending from one side to the other. This wall was built advantageously for defense and apparently designed to prevent passage of foes from the upper end of the plateau into the area where the circular rooms are situated. About midway in its length it has a passageway, the jambs of which are still visible. Three circular ruins (fig. 13) make up the cluster on the lower end of the mesa, each averaging about 15 feet in diameter, all constructed of low walls

of stones dressed into proper shape. These buildings are not connected but separated by intervals. The tops of the walls for several feet have fallen, exposing interiors which are almost completely filled with stones and rubble.

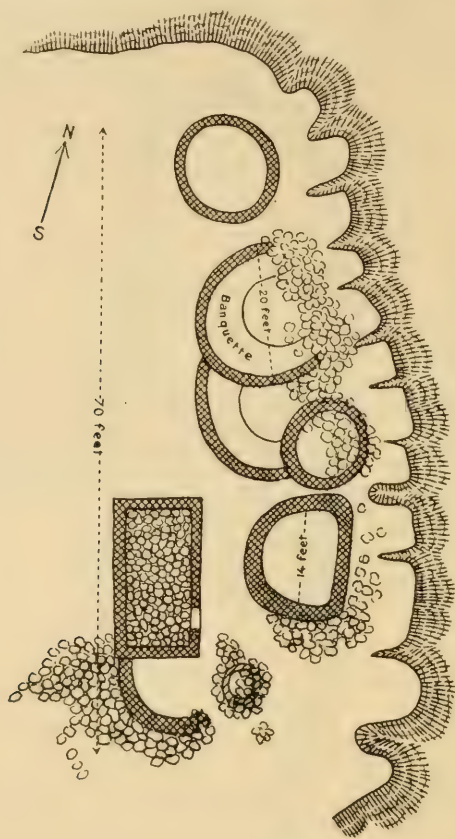


FIG. 14.—Ground plan of Eight Mile Ruin.

EIGHT MILE RUIN

Eight Mile Ruin (pl. 10) is the largest and most conspicuous of the Hill Creek remains. It consists of a cluster of towers on a cliff overlooking the right side of the canyon below Taylor's ranch and from the bottom of the canyon resembles a single large building. It is made up of several circular towers, with passageways between which preserve all the typical features of this style of ruins. When this cluster is examined individually it is found to be composed of

round rooms, a semi-circular building, and a rectangular room (fig. 14). The basal courses of the masonry are constructed of massive, almost megalithic, rocks. The walls of the rectangular building are particularly well made, and enclose a room filled to the top with clay mixed with fallen rubble. The longest side of this room extends north and south. The whole cluster is approximately 70 feet in length. The diameter of the circular rooms varies, the outside measurement of the larger ones being about 20 feet, while the smallest is barely large enough for a man to stand in with comfort. The semi-circular room is 14 feet in diameter. The axis of these rooms extends approximately in a north-south direction. So far as could be traced each of the larger circular ruins has on the inside an elevated banquette surrounding it, and enclosed in a wall, reaching a height of 10 feet. There is much fallen rock within these enclosures concealing their floors and rendering it impossible to trace properly the course of the banquette or interpret its relation. Another ruin of the same general plan, but smaller, is a little farther down on the same side of the canyon. Its walls have tumbled almost to their foundations, and are inconspicuous, resembling piles of stone.

The essential architectural feature of the Hill Canyon towers is their circular form, modified in many instances by the addition of a straight wall or rectangular annex. In certain cases the enclosing walls of two towers have fused, while in the Eight Mile Ruin the towers are accompanied by a rectangular room separated a short distance from them.

None of these towers show any evidences of past habitation and, what is remarkable, no fragments of pottery occur on the surface of the plateau in their neighborhood. Not far from the tower (pl. 10, *a*), there was picked up a mealing stone similar to those used by pueblo Indians in grinding corn, but no accompanying metate was found. No excavations were attempted.

MUSHROOM ROCK RUINS

The structure of the ruins of the mushroom rock type is not radically different from that of the towers above described, they being exceptional only in their unusual sites. They occur on top of eroded pillars of rock, often enlarged on top, reminding one of mushrooms, like the so-called Snake rock at Walpi. They were once extensions or spurs of the mesa but are now rock pillars cut off by erosion so that they stand out isolated from the rim of the canyon.

On account of the difficulty in reaching their tops, the ground plan of many could not be observed, but with a glass it was seen that as a rule they conform to the shape of the rim of the rock on which they stand. Considering the unusual sites of these inaccessible buildings, the question naturally arises, How could the ancient dwellers enter these rooms? Had they ladders or ropes, or were footholes cut in the side of the cliff to aid them? If the theory of footholes be correct we may suppose that these have been worn away, for no trace of them could be found.

A geological question might likewise suggest itself to anyone seeing the evidences of erosion between the cliffs and pinnacles. Has the gap between the latter and the edge of the plateaux been ploughed out by the water since the building on the former were constructed? Although the cliffs show that the amount of the erosion has been enormous, it must be borne in mind that the prevailing rock is soft sandstone, the wearing away of which would not necessarily require a great period of time. It is not probable that these pinnacles have been separated by erosion from the cliff since man constructed the walls upon them, but this question involves the knowledge of a geological expert.

To the same group of ruins as the mushroom type belongs one from a wholly different locality, shown in plate 12, *a*, a photograph of which was given the author by Mr. Chubbock. In this case the ruin is not built on top of a rock pinnacle, in the shape of an inverted cone, but in the horizontal fissure or constriction worn out under the harder stratum above it. The building in this cleft is in fact a kind of cliff house in which the front wall extends from top to bottom of the crevice, the rooms occupying a recess back of this wall. A somewhat similar form of habitation found in the side of a cliff has been described by the author.¹ It was discovered in the Verde Valley, Arizona, near Jordan's ranch, about 6 miles from Jerome, Arizona. In his description it is classified as a "ledge house," a type where the opening into the cave is completely walled up. Unlike a true cliff dwelling the rooms occupy the whole of a natural cave the top of which is its roof. It is not possible to determine from the illustration here shown whether or not the recess has been enlarged by artificial means, and as the author has not visited the ruin he has no idea of the arrangement of rooms.

¹28th Annual Report, Bureau of American Ethnology, pp. 198, 199.

INVERTED CONE RUIN

The best example of the mushroom type of ruin, shown in the accompanying figure (fig. 15) is about 6 miles up the canyon from Taylor's ranch on the right hand side of Hill Canyon. It is clearly visible from the road which follows the stream and has a wide out-



FIG. 15.—Inverted cone ruin.

look up and down the valley. Although the top of the rock on which this ruin stands would at first sight appear to be inaccessible, Mr. Owen, by means of a log, surmounted it and reported that its surface is flat and that the walls thereon are about 20 feet long and five feet wide, enclosing a roughly oval chamber, as their outline follows the rim of the top of the rock. These walls, when seen from the road with a good glass, appear as low ridges constructed of indifferent masonry.

TWIN TOWERS

Twin pinnacles, shown in figure 16, were observed from the road about 3 miles up the canyon from Taylor's ranch. Fragments of



FIG. 16.—Mushroom rock ruins.

walls existed on top of both of these pinnacles, but as it was impossible to reach them on account of the erosion at their bases the form and condition of the walls were impossible to determine. Like the tower

last mentioned, the view from their tops stretches several miles in both directions up and down the canyon.

RUIN ON LEANING PINNACLE

The author's limited visit to this region made it impossible to record all the various shapes of eroded pinnacles bearing buildings found in Hill Canyon, but one of the most remarkable of these foundations was observed to lean very perceptibly to one side (pl. 13) so that one side of the ruin barely falls within the line of stable equilibrium. The top of this leaning pinnacle was inaccessible, the height being about 50 feet from the base, which rose from a narrow ridge over 200 feet above the plain. The author's idea of the ground plan and character of the masonry in this ruin is limited to what could be seen from the road, but its general appearance from that distance is the same as the preceding ruin.

In this account the author has mentioned a few of the more prominent mushroom rock ruins, confining himself to those which can be observed in a hurried visit to the canyon. It is undoubtedly true, as reported by several cowboys, that the side canyons, difficult of access, concealed many others which a longer visit would bring to light. The characteristics of the ruin crowned pinnacles, or leaning buttresses of rock in Hill Canyon are shown in plate 13.

CONCLUSIONS

As artifacts were not found in or near the buildings on the Hill Canyon cliffs, and as the ruins show no evidence of former habitation, it is evident that they were not dwellings. Their use and the kinship of the people who built them can be judged only by what is left of their walls and the character of their masonry. As has been pointed out, the most prominent of these ruins are circular rooms or towers, arranged in clusters, for an interpretation of which we may look to similar architectural forms found elsewhere in the Southwest.

Their commanding position suggests that these towers were constructed for lookouts and for defense, but the questions might very pertinently be asked, Why should either of these uses necessitate three or four almost identical buildings grouped together, when one would be sufficient? Why are some of them in places where there is no broad outlook?

The massive character of the walls suggests a fortification, but why if defense were the only explanation of their use would not one large

building be preferable to many, especially as it would be more easily constructed. It might be urged that they were granaries; but if so, why were they placed in such a conspicuous situation?

In searching for an explanation for the construction of these buildings, an examination was made of aboriginal towers in the valley of the San Juan and its tributaries, especially the Yellow Jacket Canyon and those tributaries entering it on the northern side. In the Mesa Verde National Park the author has also discovered several towers which are in a comparatively good state of preservation. Some of these are situated on high cliffs, others stand in valleys hidden by dense forests of cedar.

Towers are, roughly speaking, scattered sporadically in numbers over a wide extent of country, bounded on the east by Dolores River and on the south by the Mancos River and the San Juan. They extend as far west as Montezuma Creek, following it up north as far as exploration has gone and occurring as far south as Zuñi. Rarely, if ever, however, do we find towers in the dry, sandy, wastes south of the San Juan, and they are unrepresented in the great ruins of the Chaco Canyon. Although there seemed to be certain minor differences in the construction of towers found at different places in this area of distribution, all are identical in essential features.

The towers of Hill Canyon bear a close likeness to those in the region mentioned, except that their masonry is poorer and their walls are more dilapidated. This can be ascribed in part to the material out of which they are built, for whereas the stone in the southern part of the area is soft and easily worked, that in the Hill Canyon region is hard but can readily be split into slabs which did not require much manipulation to bring them into desired shapes for use. The tall and better built towers of the San Juan (pl. 14, *a*) and its tributaries are sometimes single rooms without connections with other buildings, but are more often surrounded at their bases by rooms not unlike those of pueblo ruins. Thus at Cannon Ball ruin the towers rise from the midst of secular rooms and the same is true of the tower in Cliff Palace and elsewhere. This leads to the supposition that these buildings were constructed for some purpose other than as lookouts; they bear all the outward appearance of sacred rooms called kivas of pueblos and cliff dwellers. If we accept this explanation¹ that the McElmo towers are round kivas, as suggested by Holmes, Mor-

¹ A complete discussion of these prehistoric towers would lead to a morphological comparison with the Chulpas of Peru, the Nauregs of Sardinia, Irish and other similar religious structures.

gan, and others we can explain why several are united in a cluster, for it would seem that each room in such a cluster belonged to a family or clan. The use of these towers as here suggested can not, however, be proven until excavations of them are made and the signification of the banquette constantly found annexed to their inner wall is determined.

Several structural remains in Ruin Canyon (pl. 14, *b*), a tributary of the Yellow Jacket, especially those at the head of the South Fork, give a good idea of the relation of the tower to surrounding rooms. Here we find towers constructed of fine, well preserved, masonry rising to almost their original height, but crowded into the midst of rectangular rooms imparting to the whole ruin a compact rectangular form. Several towers in this canyon are without surrounding rooms, others have rectangular, square or D-shaped ground plans, but the author studied none with two or three concentric surrounding walls.

The form of one of the largest ruins in Ruin Canyon situated near the fork of the canyon, closely resembles Far View House, in the Mesa Verde National Park. It has a central tower around which are rooms with straight walls, the intervals between which and the circular wall of the tower having a roughly triangular shape. While there is but one tower in this ruin, its similarity in form and position to the large central kiva of Far View House indicates that towers in the McElmo are practically ceremonial rooms, as has been long suspected.

This identity in form of tower and round kiva and the relative abundance of both in the San Juan drainage, leads the author to believe that one was derived from the other, in that district, and spread from it southward and westward until, very much modified, it reached the periphery of the pueblo area. It is believed that, in the earliest time, the isolated tower was constructed for ceremonial purposes and that rooms for habitations were dugouts or other structures architecturally different from it. Later, domiciles were constructed around the base of these towers until they encircled them in a compact mass of rooms. The tower then lost its apparent height, but morphologically retained its form. As this circular type of kiva spread into the pueblo area in course of time it was again constructed independently of the domiciles and the relative numbers diminished until, as in some of the pueblos of the Rio Grande, there survive only one or two kivas for each village, but these are no longer embedded in habitations as in the more advanced archaic conditions.

The tower kiva may be regarded as the nucleus of the clan, or the building erected for ceremonies of that clan, the earliest and best

constructed stone structures in the region where the pueblo originated. Where there were several clans there were several towers; when one clan, a single tower. In course of time rooms for habitation or possibly for other purposes, clustered about these towers; these units consolidated with rooms and kivas of another type forming a composite pueblo. In this form we find the towers rising above a mass of secular rooms. The archaic form of ceremonial room or tower survived in Cliff Palace and other Mesa Verde ruins.¹

Several circular kivas and towers seen by the author have one or more incised stones, bearing a coiled figure resembling a serpent. One of the best of these has also peripheral lines like conventional symbols of feathers. An obscure legend of the Hopi recounts that the ancestral kivas of the Snake clan, when it lived at Tokonabi, or along the San Juan were circular in form. While at present only a suggestion, it is not improbable that towers and round kivas may have been associated with Snake ceremonials, especially as this cult is known to have survived among Keresan pueblos like Sia and Acoma. The Snake clan of the Hopi according to traditions came from the north or the region of circular kivas.

From their similarity in external shape and distribution, circular ruins and round towers have been regarded as in some way connected. It by no means follows that rooms inside their external walls were identical in use. For instance, the so-called Great Tower on the cliffs overlooking the San Juan, described and figured by Prof. Holmes, is said by him to measure 140 feet in diameter, and to have double walls connected by partitions, forming a series of encircling rooms. This ruin may be classified not as a tower but a circular ruin, and the same may be said of the so-called Triple-wall Tower, rising on the

¹A more extended discussion of towers is reserved for a monograph, now in preparation, on "Prehistoric Towers of the Southwest." The author has made several new observations on these structures some of which differ considerably from those of his predecessors.

Morgan, "Houses and House Life of the American Aborigines" (Contr. to Amer. Ethnol., Vol. IV), has pointed out, page 191, that the round tower at the base of Ute Mountain must have been entered through the roof, as no lateral doorways were visible, and Montgomery's observations on towers in Nine Mile Canyon point the same way. These facts tell in favor of the theory that towers and kivas are morphologically identical, as Morgan indicates. An absence of pilasters on the inner walls of towers indicates that the roof was not vaulted, as in most Mesa Verde cliff dwellings and in the pueblo, Far View House, of the Mummy Lake group. Towers belong to what I have designated the second type of kivas, or those with flat roofs, and are less abundant in the San Juan area.

border of rectangular rooms, situated at the mouth of the McElmo. The dimensions of this so-called tower are reported to be "almost" the same as the Great Tower. The author regards these as examples of an architectural type related to towers, from which it is distinguished not only by size, but also, especially, by the arrangement of rooms on their peripheries. The internal structure of the tower type is little known, but in none of these buildings has the author detected peripheral rooms separated by radial partitions, although one of these radial partitions is found in kiva A of Sun Temple. The original building of the last mentioned ruin, although D-shaped, has a morphological similarity in the arrangement of peripheral rooms to the "Great Tower" of the San Juan, or that on the alluvial flat in the Mancos, and the "Triple-wall Tower" room of the McElmo, save that the so-called innermost of the triple walls is replaced in Sun Temple by two circular walls, side by side, forming kivas B and C.

The tower, with annexed rectangular rooms, like its homologue, the circular kiva with similar adjacent chambers surrounding it, is practically the "unit type," a stage of pueblo development pointed out by Doctor Prudden,¹ who does not make as much as would the author of the intra-mural condition of the kiva, or its compact union with domiciliary rooms. Far View House on the Mesa Verde is a good example of this union of form, characteristic of the "unit type" or compact pueblo with embedded circular kivas, one of which is central, probably the first constructed, and of large size. Such compact pueblos are numerous on the Mesa Verde, judging from central depressions in mounds, and characteristic of the San Juan, at least of its northern tributaries. The previous stage in pueblo development is that in which the sanctuary or tower (kiva) and habitation are distinct. The extra-mural circular kiva,² or circular room separated from the house masses either in courts, as in Rectangular and Round villages, or situated outside the same as in "Line villages," like Walpi, or pyramidal forms, is like Zuñi or Taos and more modern pueblos. This modification is widely distributed in ruins south of the San Juan, still persisting in several modern pueblos.

The above observations have an important bearing on the author's differentiation of the village Indians of the Southwest, into two

¹ *Op. cit.*, also, The Circular Kiva of Small Ruins in the San Juan Watershed. Amer. Anthr. Jan.-March, 1914.

² The intra-rectangular kivas of such pueblos as Zuñi are comparatively modern, but their position is explained in a very different way from that of the intra-mural circular kivas characteristic of the ruins of the San Juan.

groups, which are culturally distinct and widely distributed geographically. The western group originated in the Gila Valley, and extending across Arizona spread northward making its influence felt as far as the Hopi villages; the eastern culture was born in Colorado and Utah and extended to the south along a parallel zone. The former sprang into being in low, level, cactus plains; while the latter was born in lofty mountains and deep canyons filled with caves. Each reflects in its architecture the characteristic environment of the locality of its origin. As they spread from their homes and at last came together each modified the other by acculturation. The expansion of these two nuclei of culture, and the products of their contact is the prehistoric, unwritten, evolution of primitive people in the Southwest upon which documentary accounts throw no light, and the function of archeology is to read this history through the remains left by this prehistoric people, as interpreted by surviving folklore, ceremonials, legends, and artifacts. Both types of culture reached their highest development before the arrival of the white man; and the advent of the European found both on the decline. The localities where both types originated and reached their highest development were either no longer inhabited or occupied by descendants with modified architectural ideas. Some of the survivors lived in houses of much ruder construction than the cliff dwellings or pueblos of their ancestors. The habitations of others were scattered rude, mud huts. In short the cliff dwellers of the Mesa Verde and the prehistoric inhabitants of the Gila compounds left survivors possessed of inferior skill. Both architecture and ceramic art had declined before the advent of white men.



TEBUNGKI FIRE HOUSE, ARIZONA.



a



b



c

CLIFF DWELLINGS IN CHIN LEE CANYON, ARIZONA.

a, b, Ruin A.

c, Ruin B.

(Photographs by G. H. Hoater.)



a



b



c

SITES OF RUINS NEAR GALLUP, NEW MEXICO.

- a, Zuñi Hill Ruin.
- b, Black Diamond Ranch Ruin.
- c, Kiva of Zuñi Hill Ruin.



a



b

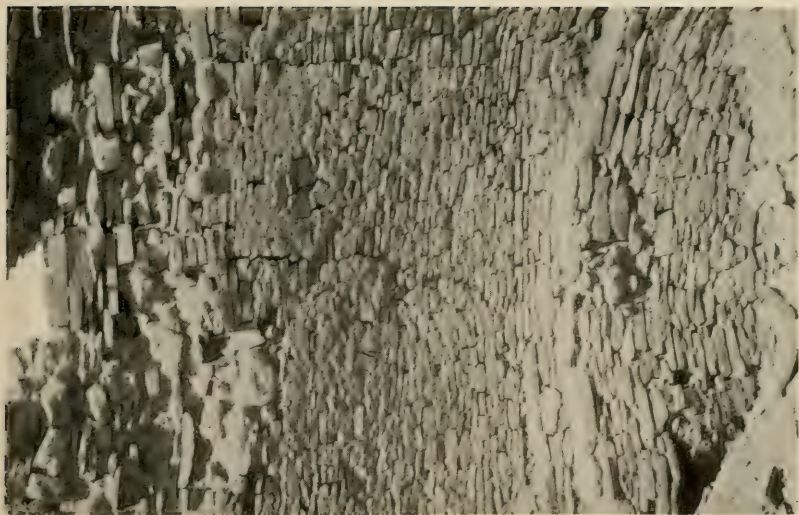


c

KIN-A-A, CROWN POINT, NEW MEXICO.

a, b, From west.

c, Showing mounds near Kiva.



a



b

KIN-A-A.
a, Inner wall of second story of Kiva.
b, Outer wall of Kiva.



a



b

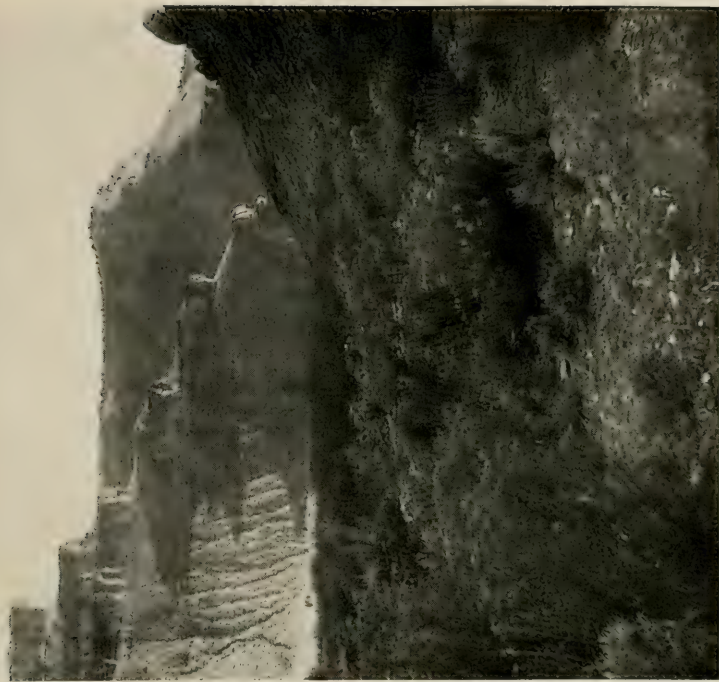
CROWN POINT, RUIN B.

a, From east.

b, From north.



a



b

HILL CANYON UTAH.
a, Ruins A and B.
b, View up the canyon.
(Photographs by T. G. Lemmon.)



a



b

RUINS NEAR TAYLOR'S LOWER RANCH, HILL CANYON, UTAH.

a, Ruin A.

b, Ruin B.

(Photographs by T. G. Lemmon.)



a



b

LONG MESA, HILL CANYON, UTAH.

a, From north.

b, From south.

(Photographs by T. G. Lemmon.)



a



b

EIGHT MILE RUIN, HILL CANYON, UTAH.

a, From south.

b, From west.

(Photographs by T. G. Lemmon.)

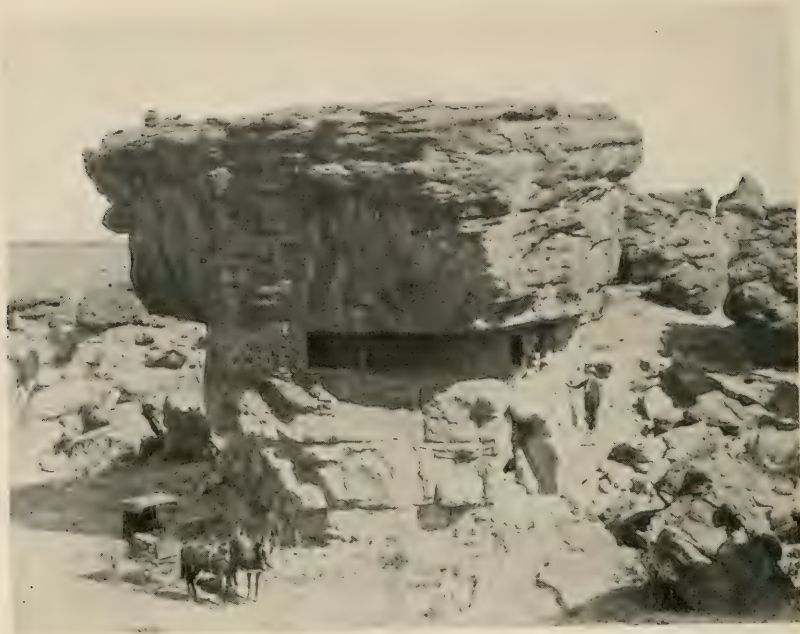


a

a, Storage room, Hemlock Canyon, New Mexico,
b, Mushroom Rock without ruin on top, McElmo Canyon, Utah.



b



a

(Photograph by Chubbuck.)



b

(Photograph by T. G. Lemmon.)

a, Ledge House in cleft of mushroom rock.
b, Tower in cedars near Sprucetree House, Mesa Verde National Park.



RUIN ON ROCK PINNACLE, HILL CANYON.



a



b

RUINS IN SOUTHFORK, RUIN CANYON, UTAH.

a, Twin Towers.

b, Towers and buildings.

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RECOGNITION AMONG INSECTS

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INTRODUCTION

It has always been a matter of conjecture as to how the various lower animals recognize each other, and by what means the sexes of any species distinguish one another. At first thought it might be claimed that sight is the chief means by which any animal having eyes can recognize other animals, but after a second thought we recall that the eyes in the lower animals are not as highly developed as they are in the higher animals; and we know that many of the lower animals live in dark places and that some of them are partially or totally blind. For example, the eyes of some beetles and spiders inhabiting caves function little or not at all, and despite this fact, these animals seem to distinguish one another as easily as do those with normal eyes living in light places. Relative to blind or partially blind species, touch may be the chief means by which they recognize one another, but during the courtship of cave spiders the writer (1910) observed that the males recognize the females of the same species at short distances and even before the males touch the webs of the females. Touch, therefore, can not be the chief means of recognition for cave spiders and perhaps not for any other animal. Since we know so

little about the senses of hearing and taste in the lower animals, we may safely eliminate them as the chief factors in recognition.

That the lower animals do recognize one another without using the tactile organs, and as their sense of sight is not sufficiently developed to be the chief factor in recognition, we may assume that the most important factor is some chemical sense, perhaps similar to our olfactory sense. If the olfactory organs are the chief means of recognition, they must constantly receive stimuli in the form of odors, and these odors must be emitted by the animals themselves. If this is true, it would seem that the odor emitted by one animal should be at least slightly different from that of any other animal, and reasoning in this way Jaeger (1876) believes that most animals emit odors peculiar not only to the individual, variety, race, and species, but also to the genus, family, order, and class, and that these odors are the chief means by which one animal recognizes other animals. Without the aid of the eyes he claims that the degenerate human olfactories are able to distinguish a horse from a cow, a goat from a roe, a dog from a cat, a martin from a fox, a crow from a pigeon, a parrot from a hen, a lizard from a snake, and even a carrion crow from a hooded crow. Blackman (1911) remarks that the anal mucous membrane of our domestic animals, particularly the dog and cat, contains glands whose secretion emits a comparatively mild odor which probably serves as a secondary sexual purpose, but in other carnivores, such as the otter, badger, wolverine, mink, martin, ferret, ermine, weasel, and skunk, the scent may be far from mild and in many cases is used either as a means of defense or offense.

The chief object of the present paper is to show that the chemical sense (usually called the olfactory sense) in the lower animals, but particularly in the honey-bee, is so highly developed that we do not have any more conception of it than does the honey-bee (if it could think as we do) of our wonderfully developed sense of sight which is able to distinguish accurately the size, form, and color of objects.

If recognition among the lower animals is accomplished by means of odors stimulating the olfactory organs, then these animals must have means of producing the odors, and therefore such organs may be called scent-producing organs. The experimental results embodied in the present paper are mostly from observations made upon the honey-bee by the writer, while the part dealing with the scent-producing organs is a brief historical review of the literature on this subject.

ODORS EMITTED BY INSECTS

Our experiences with the higher animals prove that practically all of them emit odors, which in most cases probably play a secondary rôle to that of sight, but it is shown in the following pages that the odors emitted by the honey-bee are the chief means of recognition.

A. ODORS EMITTED BY THE HONEY-BEE

It has always been more or less a matter of conjecture as to just how the different individuals of a colony of bees recognize one another. Considering the five special senses of sight, hearing, touch, smell, and taste which we experience, we may safely eliminate taste, because the writer has recently (1916a) shown that bees do not have a true gustatory sense, for it is only one phase of the olfactory sense. Since it is more or less dark inside the hive, sight certainly can not play a very important part in recognition, and since it has never been proved experimentally that bees can hear we can not consider hearing as the chief factor, and despite the fact that the writer (1916a) has demonstrated that the tactile sense is quite acute, the sense of touch in all probability is not as important as is the sense of smell. The following pages give the experimental results concerning the power of recognition among bees, which were brought about by means of the olfactory sense, and the rôle played by the other senses is not considered.

Relative to the odors emitted by the honey-bee, von Buttel-Reepen (1900) says:

I believe that the following odors are present in a colony of bees:

1. The individual odor. It can be easily demonstrated that the queen odor varies with different individuals, and on the same ground (germinal variation), an individual odor should be assigned to the workers.

2. All offspring of one mother (queen) have a common inherited family odor in addition to the individual odors, belonging only to the progeny of one queen.

3. The brood and chyle odor.

4. The drone odor.

5. The wax odor. Since the wax is a glandular secretion, an exuded product, it may be safely taken for granted that, considered apart from the specific odor of wax, the individual odors of the wax-generators adhere to the honey-comb. Accordingly the wax structures of different colonies have different odors.

6. The honey odor. That the honey of each colony (mixed with a secretion of the salivary glands) has its specific odor is readily seen from the old practice of bee-keepers to which Bethe also alludes. If a queen be daubed with honey from a queenless colony, she will be accepted readily by that colony when inserted.

7. The hive odor (exhalation odor, colony odor). The hive odor is composed normally by a mixture of the preceding odors, or of some of them. Single bees, therefore, besides their individual odors, possess the family odor and especially the common adhering hive odor, which forms the dominant factor in the various actions toward hive mates and hive strangers—that is, in mutual recognition between bees.

Von Buttel-Reepen furthermore describes an abnormal hive odor which is caused by abnormal conditions among the occupants of the hive, and abnormal odors which are generated by disease (dysentery, foul brood, etc.).

To support the preceding views, von Buttel-Reepen gives no proofs other than his experiences as a bee-keeper, which are far from being conclusive, and the present writer, who has experienced much difficulty trying to prove his views experimentally, has had only partial success.

To know the part that odors play in the behavior of bees will be of considerable importance to bee-keepers, because the introduction of queens, uniting, and various other manipulations may be performed more successfully.

I. ODORS EMITTED THAT MAY BE PERCEIVED BY A PERSON

From April to October, 1913, the writer devoted practically all his time to a study of the odors produced by the honey-bee, and not being satisfied with some of the results obtained, several of the experiments were repeated the following summer. When this study was first begun, only the more pronounced odors—the hive or bee odor, brood odor, honey odor, and wax odor—could be distinguished by the writer, but before the close of the first summer he was able to distinguish the three castes of bees merely by smelling them. The details are as follows:

Old workers constantly give off the characteristic bee odor; and when seized, they emit another distinct odor which comes from the poison ejected through the sting. No difference between the odor of a guard and that of a fanner could be distinguished; the odor from each closely resembles the hive odor, that is, the odor which comes out of a hive when the hive cover is removed. A worker carrying pollen gives off besides the bee odor another odor which comes from the pollen.

The younger the workers the less pronounced is the bee odor emitted. To the human nose the odor emitted by nurse bees and wax generators is much less pronounced than is the odor from old workers.

Workers just emerged from the cells have a faint sweetish odor, but lack the characteristic bee odor, and workers removed from the cells just before they begin cutting their way out emit a fainter sweetish odor.

Old queens have a strong, sweetish odor, while the odor from queens just emerged from their cells is much less pronounced. The queen odor is very pleasant and is as characteristic for queens as is the bee odor for workers.

The majority of old drones have a faint odor, while almost every young drone has a stronger odor. This odor is slightly different from that of young workers and is less sweetish.

While considerable experience was required of the writer before he was able to distinguish differences between the odors emitted by the three castes and only slight differences or none at all between the odors emitted by different individuals of the same caste, the following experiments show that this power of distinguishing odors is quite different with the bees themselves.

2. HIVE ODOR

To determine if workers carry the hive odor and to ascertain the significance of this odor if carried by them, one-half the frames and about two-thirds of the bees were removed from hive No. 5, and were placed in a new hive some distance from the old one. The brood, honey, and pollen were divided as equally as possible and the queen was left in the old hive. The queen was a year old and this colony had never been united, so that probably nearly every worker in this hive was a daughter of this queen. The old and new hives may now be called hives No. 5a and 5b respectively.

To ascertain if the workers in these two hives had become enemies¹ eight days after hive No. 5 had been divided, ten triangular glass observation cases were constructed. These were made of three narrow wooden strips, two of which were 10 and the third 6 inches long, each being half an inch wide. Cheese-cloth served as bottoms and glass as tops for the cases. The apices and bases of these cases rested on two supports above a rigid table and the table legs rested on a concrete floor, near a window.

Twenty middle-aged workers from a frame in hive No. 5b were put into each of these cases. Ten middle-aged workers were removed

¹The words enemy and friend here as elsewhere in this paper are used anthropomorphically owing to lack of more appropriate terms.

from a frame in hive No. 5a. One of these 10 bees was put into each case; all 10 were attacked quite forcibly. This proves that the bees from these two hives had become enemies.

To determine if these sister bees, which had become enemies by having their original colony divided, could be made friends again, ten cases similar to those already described were used. These cases, however, were an inch deep and wire screen served as tops and bottoms. These cases were numbered 1 to 10 and may hereafter be known as the wire-screen cases.

Fifty middle-aged workers were removed from a frame in hive No. 5a and were placed in each of three of these cases (Nos. 1 to 3). Fifty workers from a frame in hive No. 5b were likewise placed in each of three more of these cases (Nos. 4 to 6). As controls 50 middle-aged workers from a frame in hive No. 29 were placed in each of two more of these cases (Nos. 7 and 8), and in a like manner 50 workers from hive No. 49 were placed in two more of these cases (Nos. 9 and 10). A large lump of queen-cage candy (made by kneading confectioner's sugar in a small amount of honey) was kept continually in each case. A piece of cotton wet with water was also constantly kept in each case. The cases containing the bees from hive No. 5a, one of those containing bees from hive No. 29 and one of those with bees from hive No. 49 were kept in the south room of the laboratory, while the other five cases were kept in the north room of the laboratory. The apices and bases of these cases rested on supports above rigid tables by open windows so that the air could pass freely through the cases.

Three days later a worker from each of cases Nos. 4 to 6 was put into each of cases Nos. 1 to 3; likewise, a worker from each of cases Nos. 1 to 3 was put into each of cases Nos. 4 to 6. All six introduced bees were received peacefully without even the least signs of hostility. This proves that these sister bees had become friends again, provided they responded normally. To test this possibility, 15 minutes later a worker from hive No. 23 was put into each of the six cases; all six introduced bees were attacked quite forcibly. After another interval of 15 minutes a worker from a frame in hive No. 5a was put into each of the six cases; all six introduced bees were attacked quite forcibly. Fifteen minutes later a worker from a frame in hive No. 5b was put into each case; as usual, all six introduced bees were attacked quite forcibly. An hour later still workers from cases Nos. 7 to 10 were put into these six cases; all six introduced alien bees were attacked only lightly.

Concluding from the foregoing experiments, the following conditions are indicated: Hive No. 5 had a hive odor and after this colony had been divided eight days each new colony thus produced had formed a new hive odor different from the hive odor of the other new colony. The workers of any colony carry the hive odor formed by their own colony. After a confinement of three days in the wire-screen cases, workers do not produce a new hive odor, but lose the hive odor that they bore when removed from their hive. That they are not able to form a new hive odor in these cases and that they lose the hive odor carried by them is probably due to air constantly passing through the cases. The workers, therefore, from hives Nos. 5a and 5b confined in cases Nos. 1 to 6 became friends again because their respective hive odors had disappeared, and they failed to attack each other even lightly because they were offspring from the same mother. These workers fought those from cases Nos. 7 to 10 only slightly because the latter had lost their respective hive odors and the slight hostility exhibited was due to the fact that the bees in cases Nos. 7 to 10 were offspring from different queens.

The foregoing experiments were repeated three times with bees from hives Nos. 5a and 5b. Each of the three lots of bees was put into cases Nos. 1 to 6 as already described for lot No. 1 in the preceding experiments and workers used as controls from different hives were put into cases Nos. 7 to 10 as before described. After a confinement of three days in the cases all of these workers were tested. Of the 18 workers tested one at a time from hives Nos. 5a and 5b, 16 were received peacefully without the least signs of hostility; the bees showed slight signs of hostility toward the other two but did not attack them. On the fourth day after confinement 18 more workers were tested one at a time; all 18 were received peacefully without signs of hostility. After a confinement of only one day in these wire-screen cases and when tested one at a time, each introduced bee was attacked only lightly. The workers used as controls in all of these experiments were tested and the results were always the same as described for the first lot.

Hive No. 73 was equally divided on October 15, making two new colonies, Nos. 73a and 73b. The brood, honey, and pollen were also divided as equally as possible and the queen was left in the hive on the old stand. Five months previously this colony had been united whereby strange bees from another queen were mixed with those already in this hive. By October 15, all the bees added by uniting were certainly dead. Three days after the colony had been divided,

workers from hives Nos. 73a and 73b were placed in the glass observation cases as already described for bees from hives Nos. 5a and 5b. Upon testing them it was evident that they had become enemies and the hostility was certainly due to the hive odor carried by the bees from their respective hives.

Workers from hives Nos. 73a and 73b were put into wire-screen cases Nos. 1 to 6, and workers used as controls from hives Nos. 40 and 80 were put into wire-screen cases Nos. 7 to 10. After a confinement of four days in these cases they were tested as usual. The results were the same as those described for the bees from hives Nos. 5a and 5b.

Hive No. 7 was formed by uniting two colonies on May 25. On September 2, this colony was equally divided and at this date it very probably contained workers which were the daughters of two queens. Six days after the colony had been divided, workers from the two new colonies, Nos. 7a and 7b, were quite hostile to each other. Workers from hives Nos. 7a and 7b were put into wire-screen cases Nos. 1 to 6, and workers used as controls from hives Nos. 44 and 72 were put into wire-screen cases Nos. 7 to 10. After a confinement of seven days in these cases they were tested. Of the six introduced workers from hives Nos. 7a and 7b, five were received peacefully while one was attacked slightly. The results obtained by using the controls were the same as those for the other controls as already described.

On July 17, colony No. 56 was made by uniting eight frames containing bees, brood, and stores from four different hives. The bees, therefore, were offspring from at least four different queens. This hive did not thrive well because much difficulty was experienced in getting a good laying queen accepted. On August 19, this colony was equally divided. Four days later the bees in the two colonies, Nos. 56a and 56b, had become enemies. Three lots of workers from hives Nos. 56a and 56b and workers from various other colonies were put into the wire-screen cases as usual, and were tested on or after the third day of confinement. Of the 18 workers tested from hives 56a and 56b, five were received peacefully and the bees did not even attempt to attack them; they attempted to attack seven others, but did not seize them; five others were attacked lightly, and one other was attacked considerably. The results obtained by using the controls were the same as in all the foregoing experiments.

It should be stated that all the controls, described for the first lot of bees from hives Nos. 5a and 5b, were also employed in all of

the other experiments, and the results obtained are practically the same. The time of introducing a bee to be tested in the various sets of experiments was so alternated that no error in regard to the sequence of time of introducing could have affected these results.

The following experiments were performed to determine the gradual change in the hive odor: On May 20 at 11 o'clock, colony No. 2, swarmed, and the swarm was placed in a new hive (No. 26). Twenty-four hours later 20 workers from a frame in hive No. 2a (the old hive) were put into each of the 10 observation cases, then 10 workers from a frame in hive No. 2b were tested as usual. Of the 10 workers tested, six were received peacefully; the bees showed signs of attacking one; and three were attacked slightly. Forty-eight hours after the bees had swarmed, the preceding experiment was repeated. Of the 10 workers tested, three were received peacefully; four were attacked slightly; and three were attacked considerably. Seventy-two hours or on the third day after the bees had swarmed, nine of the ten bees tested were received hostilely.

The foregoing experiments were repeated by using workers on the first, second, and third days after colony No. 82 had been equally divided. On the first day after the colony had been divided, four workers were received hostilely; on the second day seven were received hostilely; and on the third day all 10 of the workers tested were attacked. Similar results were also obtained by using bees from seven other colonies which had been divided.

All the foregoing experiments seem to prove that each colony of bees has its own particular hive odor and when a colony is divided each portion forms a hive odor different from that of the other portion, and also different from the hive odor of any other hive and probably different from that of the original hive, and the new hive odor is formed gradually and is sufficiently different at the end of the third day from that of any other hive to cause total hostility. The hive odor is carried by the workers and disappears in three days when the workers are confined in wire-screen cases.

The bees in the wire-screen cases described under hive odor, will also be discussed under individual and family odors.

(a) FUNCTION OF HIVE ODOR

Concluding from the experiments dealing with the hive odor, the success attained in uniting bees from two or more colonies in order to increase the number of colonies depends upon the formation of a new hive odor. When first united the new colony will contain just

as many hive odors as there are colonies from which the bees were taken. To have peace among the different members of the new colony, a new hive odor, common to every individual in the hive, must be produced. The new hive odor is brought about by a thorough mixing of all the old hive odors with all the individual odors (see pp. 13 to 19) emitted by the members of the new hive, and success is more readily attained when smoke is added.

In practical bee keeping it is impossible to have an emerged queen devoid of a hive odor. So soon as a queen emerges from her cell she mingles with the workers and soon takes on the hive odor. To introduce an emerged queen into a foreign hive by the indirect method, she is put into a queen cage, which is then placed inside the foreign hive. By the time the workers have eaten through the candy to her, she has lost the hive odor that she previously carried and has taken on the hive odor of the foreign hive.

No difficulty is encountered on account of the hive odor when a queen cell, containing a queen ready to emerge, is transferred from one hive to another, because such a queen carries little or no hive odor.

The introduction of queens by means of the direct method is simple. The hive is filled with smoke, the queen is then run into the hive, and the entrance is closed. The smoke confuses the workers and throws them into a state of excitement, causing them to fill themselves with honey. More smoke is blown into the hive, and by the time the workers have become quiet, the introduced queen has taken on a sufficient amount of their hive odor to protect her.

(b) IMMERSION TO DESTROY HIVE ODOR

In view of the fact that the hive odor is probably the most important factor employed in the maintenance of the social life of a colony of bees, it is at the same time the most perplexing factor that man has to contend with in dealing with bees. This is due to the fact that uniting, introducing queens, etc., are artificial manipulations, and the processes involved are not in accord with the natural laws.

If the hive odor can be eliminated before such manipulations are undertaken, the difficulties encountered in uniting and in the introduction of queens might be overcome. To ascertain whether the hive odor may be destroyed by immersing bees in various liquids, the following experiments were performed. Twenty workers from the alighting board of hive No. 14 were placed in each of the 10 glass observation cases. Ten workers from the alighting board of hive

No. 28 were put into a queen cage and the cage with bees was immersed in water for 15 minutes. The apparently lifeless bees were then removed from the cage and were allowed to become dry. When dry and when they could walk and fly normally, one of them was introduced into each of the 10 cases. This set of experiments was repeated seven times. Of the 80 immersed workers tested, 40 were attacked more or less and 40 were received peacefully, although the bees seemed to regard some of the latter also as strangers. As a control the bees placed in the cases were taken from a frame of hive No. 25, and 10 guards from the entrance of the same hive were immersed in water for 15 minutes. When dry one of the immersed guards was introduced into each case; six of them were attacked lightly and four were received peacefully, although they were cleaned roughly.

Workers immersed in 5 per cent alcohol for one minute and then in water for 14 minutes were invariably attacked when introduced among strange bees; in all 30 such workers were tested.

Workers from a frame of hive No. 36 were put into the cases and 10 workers from the entrance of the same hive were immersed in 10 per cent alcohol for five minutes and then in water for 10 minutes. When these immersed bees were tested all were attacked.

Twenty workers from each of hives Nos. 15 and 17 were placed in the queen cages. They were immersed in 10 per cent alcohol for five minutes and then in water for 10 minutes. When dry each lot was put into a case, and later when mixed they were still hostile to each other. This set of experiments was repeated by taking two lots of bees from the entrance of the same hive. This time the bees were immersed in 10 per cent alcohol for 10 minutes and then in water for 10 minutes; all 40 revived as usual. When mixed they were not hostile to each other, but when strange workers were introduced, the strangers were attacked. The immersed bees also attacked hive mates taken from the entrance of their own hive. This experiment was repeated by immersing 200 bees from the entrance of hive No. 56. These workers were later quite hostile to strange bees as well as to hive mates.

Fifty workers from a frame each of hives 38a and 38b were immersed in each of 10 per cent alcohol and water for 10 minutes. When dry each lot of bees was placed in a wire-screen case. A hive mate that had been confined with others in a wire-screen case for four days and that by test had lost its hive odor, was placed in each case of immersed bees. Each introduced bee was attacked quite

forcibly. This experiment was repeated once; one bee tested was received peacefully and one was attacked slightly.

Twenty workers from hive No. 60 were placed in each of the 10 observation cases. Twenty-five workers from the entrance of hive No. 19 were immersed in carbolic acid (one quart of water containing four drops of acid) for 10 minutes and then in water for 20 minutes. When dry one immersed bee was put into each of the above cases; nine were attacked and one was cleaned roughly. Upon repeating this experiment once all 10 were attacked.

Strange drones were tested in the same manner as described above. Thirty were immersed in water for 15 minutes and when dry one was put into each case as usual; 14 were attacked and 16 were received peacefully. Thirty strange drones were immersed in 5 per cent alcohol for one minute and then in water for 10 minutes. When tested, 26 of the immersed drones were attacked and four were received peacefully.

Concluding from the preceding results, it is not known whether the immersion of the bees in the liquids employed eliminated the hive odor which they carried, or whether it was merely changed, but the latter view seems the more reasonable. At most this method of procedure does not seem to have any practical significance relative to eliminating the hive odor carried by queens so that they may be more successfully introduced. It would be of interest to know the effect on the introduction of queens should they first be subjected to harmless gases before they are introduced.

3. INDIVIDUAL ODOR

On the preceding pages it is stated that each colony of bees has its own characteristic hive odor; also, a new or different hive odor may be formed in three days, and after confining workers three days in wire-screen cases the hive odor carried by them from their hives disappears and the bees are unable to form a new hive odor in these cases.

To determine how a new or different hive odor is formed, the following experiments were carried on at the same time with the experiments described on the preceding pages. Two cases similar to the wire-screen cases were employed, but these had tight-fitting bottoms and tops made of cheese-cloth and glass; they were placed flat on top of a table. To start with workers bearing as little hive odor as possible, 60 cells, all in the same comb of hive No. 60 and containing workers just ready to emerge, were uncapped with a pair of

forceps. The bees were then gently removed from their cells and 30 were placed in each of the two cases (Nos. 1 and 2), and a piece of candy and a piece of cotton wet with water were also put into each case. Six days later a worker was taken from case No. 1 and was put into case No. 2; then a worker from case No. 2 and was put into case No. 1; both introduced workers were attacked lightly. After an interval of five minutes the following controls were used: Two sister workers just removed from sealed cells of hive No. 60 were put into these cases; both were attacked slightly. Five minutes later a fanner from the entrance of hive No. 60 was put into each case; each introduced fanner was attacked lightly. Five minutes later still a fanner from the entrance of hive No. 19 was put into each case; again each fanner was attacked slightly. After a confinement of nine days in these cases the young workers were quite hostile to each other.

That a lot of isolated sister bees can not form a new hive odor unless confined in a container with close-fitting walls is evident, because the sister bees in wire-screen cases Nos. 1 to 3 were often tested in the same manner as described above after a confinement of several days. They never showed signs of hostility, and the same may be said about the sister bees in wire-screen cases Nos. 4 to 6, and about those in cases Nos. 7 and 8, and also about those in cases Nos. 9 and 10.

The foregoing experiments were repeated by using workers 21 days old, when just ready to emerge from sealed cells. They were confined in a wire-screen case for 21 days. On the first day after being put into the close-fitting cases Nos. 1 and 2, they were slightly hostile to one another; on the fourth day they were considerably hostile and on the sixth day they attacked one another still more.

These experiments were repeated by using workers bearing a hive odor. One hundred middle-aged workers, all from the same frame in hive No. 49, were put equally into the two close-fitting cases Nos. 1 and 2. After a confinement of three days in these cases they were tested in the usual manner; the bees attempted to attack both introduced sister workers. One hundred more sister bees from the same hive were used in the same manner; on the third day when tested, one introduced bee was attacked quite forcibly and one was attacked lightly. One hundred sister workers from hive No. 56 were likewise used; on the third day of confinement when tested, they showed no signs of hostility toward one introduced bee, but attempted to attack the other one; on the fourth day they were slightly hostile

to two more of their sisters. One hundred workers from hive No. 19 were likewise tested on the fifth day; they attempted to seize one introduced bee and to sting the other one when introduced. One hundred workers from hive No. 23 were also tested on the fifth day; they attempted to attack one introduced bee and did attack the other one lightly; on the thirteenth day two more were attacked lightly. One hundred workers from hive No. 73 were tested on the seventh day; both introduced bees were attacked lightly.

According to the foregoing experiments it is evident that 30 or more workers confined in a close-fitting case are able to form a new hive odor. This hive odor on the third day differs enough from that formed in another similar case by sister bees to cause the bees to attack each other more or less. The longer the bees are confined in such captivity the more hostile they are to each other, however, on about the tenth day of confinement middle-aged workers become black and shiny, and their abdomens are much distended, due perhaps to an accumulation of waste matter in the intestines. After the tenth day their hostility does not usually increase because the bees from then on gradually become less active. These results indicate that each worker emits an odor which is at least slightly different from that emitted by any other worker, and if this is true the hive odor is chiefly composed of a combination of all the individual odors.

Experiments dealing with the individual odor of bees were performed on a larger scale by employing two Benton queen-mating boxes and two wire-screen cages. The inside dimensions of a queen-mating box are 15 by 9 by 9 inches. Small frames made purposely for these boxes were used in the same manner in which full-sized frames are used in standard hives. Each box has a cover which fits rather snugly. The entrance was closed with wire screen and the feed box was filled with water. Each cage consists of a frame work made of narrow wooden strips nailed firmly together, and all six sides of the frame work are covered with wire screen. The inside dimensions of each cage are 12 by 10 by 10 inches. The cubical contents of a box and of a cage, therefore are practically the same. Small frames belonging to the queen-mating boxes were suspended in the cages and a small tin pan containing water was put on the floor of each cage. The four containers may be called boxes Nos. 1 and 2, and cages Nos. 1 and 2.

Two frames with nice comb containing much honey and pollen were removed from hive No. 81. Each comb was equally divided into halves and each half was inserted into one of the small frames and

then the frame with comb was put into one of the containers. Next, a half frame of bees from hive No. 81 was shaken into each container, the lid of the container was then securely fastened and all four containers were placed on hive bodies inside the laboratory by an open window so that the wind could blow through the cages.

Four days later 20 workers from cage No. 1 were put into each of five glass observation cases already described, and then one worker from cage No. 2 was put into each of these five cases. Twenty workers from cage No. 2 were put into each of five other glass observation cases, and then one worker from cage No. 1 was introduced into each of these five cases. No signs of hostility were shown toward any one of the 10 introduced workers. A few minutes later a sister worker from a frame in hive No. 81 was put into each of the 10 cases. The bees showed no signs of hostility toward one introduced worker; they lightly attacked seven; and two were attacked quite forcibly. After confining the bees in the cages seven days, the experiments were repeated and the same results were obtained. A few minutes later sister bees from boxes Nos. 1 and 2 were put into the cases. Eight of the introduced workers were attacked lightly and two were attacked considerably.

After confining the bees seven days in the queen-mating boxes, they were tested in the same manner as described for the bees from the cages. Of the 10 workers introduced, four were attacked lightly and six were attacked considerably.

After confining bees in these boxes and cages seven days they become more or less black and shiny and the abdomens are much distended with waste matter in the intestines. They are less active than usual and are perhaps more or less abnormal in some ways but after being confined seven to ten days, they seem to respond to odors normally.

All of the foregoing experiments were repeated by using bees and comb from hive No. 67. In these experiments, however, 20 workers from one cage were placed in each of the 10 cases and a worker from the other cage was introduced a few minutes later into each case. Thus for the cages, 20 workers, one at a time were put into the cases and all of them were received without any signs of hostility. The same procedure for the boxes was followed, and of the 20 workers introduced, the bees attempted to attack two; 10 were attacked lightly; and eight were attacked quite forcibly. When several of the workers from the boxes were placed on the alighting board of their own hive (No. 67), some of them were attacked by

their sister guards and when a guard from the alighting board of their own hive was introduced into each case containing workers from the cages, 11 guards were attacked lightly and nine were attacked quite forcibly.

The experiments with bees in the boxes and cages further substantiate the view that a new hive odor may be formed in three days when middle-aged bees are confined in a container having tight-fitting walls, and that the hive odor must be composed of a combination of all the odors emitted from the individual bees. Also, when bees are confined in a container having wire-screen sides, no hive odor can be formed, because the air passing freely through such a container carries away the individual odors just as fast as they are given off by the bees. Furthermore, sister workers are hostile to sisters of any age if the latter are mostly devoid of a hive odor, or if they carry a hive odor which is slightly different from the hive odor of the former. Several workers just emerged from their cells, if confined in a close-fitting case, may accumulate a hive odor by the fifth or sixth day. This hive odor differs enough from that formed by other sister bees of the same age in another similar case to produce hostility when the sisters from the two cases are mixed.

To ascertain if workers confined singly for a few days in close-fitting cases are able to form hive odors, and to furnish another proof, if possible, whether a hive odor is nothing more than a combination of the various individual odors, the following experiments were performed: Nineteen small triangular observation cases were constructed. Two of the sides were 5 inches and the third side was 4 inches in length. The depth was $\frac{1}{2}$ inch, the top was glass, and the bottom was wire screen.

To be sure that young workers bearing as little hive odor as possible might be used, half of a comb containing just emerging bees was removed from hive No. 19 and was placed in one of the cages described on page 15. Five days later most of the bees had emerged and two days after this date one of these young workers was introduced into each of the 19 cases. When put into these cases they had been emerged probably four or five days on an average and were sufficiently old to possess the characteristic bee odor. A small piece of candy and a small piece of cotton wet with water were also put into each case. A thick cloth was spread out on top of a table and these cases were put side by side on top of this cloth, then another cloth was spread over the tops of the cases. After a confinement of four days in these cases, five of the bees had died, and the remaining

14 live ones were tested. They were grouped in pairs by one being removed from its own case and then being introduced into another case containing a sister. When first put together, three pairs attempted to fight, but soon became friends; two pairs fought lightly; one pair fought quite forcibly; and one pair fought fatally. These experiments were repeated once by using 19 more of the same lot of bees from the same cage. The bees by this time were probably eight or nine days old on an average. After being confined singly four days, all were dead but eight; these were tested as usual. Two pairs showed no signs of hostility; one pair attempted to fight; and one pair fought lightly.

The foregoing experiments were repeated by employing middle-aged workers which had been confined three or more days in one of the wire-screen cases. As already shown these bees had lost the hive odor. After a confinement of four days in the small observation cases, three of them had died; the remaining 16 were tested as usual. Two pairs fought fatally; one pair attempted to fight, and five pairs showed no signs of hostility. This set of experiments was repeated twice with middle-aged sister workers that had lost the hive odor by being confined in a wire-screen case. After a confinement of four days, only 26 live ones for both sets remained and they did not appear entirely normal. When tested 10 pairs of them showed no signs of hostility; one pair attempted to fight; one pair fought quite forcibly, and one pair fought fatally.

The small cases described above were discarded and 50 smaller ones were constructed. Two sides of the latter cases were 4.5 inches and the third side was 3.5 inches in length, the bottoms being wood and the tops glass. The tops and bottoms fit so snugly that practically all of the odor emitted by a bee remained inside the case. After confining a single middle-aged worker from frame D of hive No. 67 in each of these cases for nine days, the remaining live bees were tested as usual. Three pairs showed no signs of hostility; three pairs attempted to fight; two pairs fought lightly; four pairs fought quite forcibly; seven pairs fought fatally, whereby in one case both bees were killed. When these results had been recorded, the remaining live bees were again placed singly into the cases, and an hour later a sister bee from frame D of hive No. 67 was introduced into each case. Twenty-seven pairs showed no signs of hostility; three pairs fought slightly; and one pair fought quite forcibly.

The preceding experiments were repeated by using middle-aged workers from a frame of hive No. 19. After a confinement of six

days, the remaining live bees were tested. Ten pairs showed no signs of hostility; three pairs fought slightly; one pair fought quite forcibly; and five pairs fought fatally.

The tops and bottoms of the 50 small cases were removed and wire-screen tops and bottoms were used in order to have open cases. A middle-aged worker from a frame of hive No. 67 was put into each case. The cases were then placed side by side on supports near an open window so that the air could pass freely through the cases. Since it was too cool for this kind of experiment most of the bees died, but after carrying on two sets of these experiments the following data were obtained: Three days after being thus confined, seven pairs showed no signs of hostility; seven pairs fought lightly; three pairs fought quite forcibly and three pairs fought fatally. The hostility that resulted may have been due to the hive odor that had accumulated during the nights, because the cases of bees were left wrapped in cloths from 4.30 p. m. till 9.00 a. m.

4. FAMILY ODOR

To determine whether the honey-bee emits a family odor, the following experiments were performed. The observation hive (No. 81) became queenless about June 19, and since it contained no eggs and no brood except worker pupæ and few drone pupæ about ready to emerge on this date, two frames containing eggs and young larvæ removed from hive No. 23 were added to it. By June 26 almost all of the brood in this hive was sealed and no eggs nor young larvæ were seen, and on this date a virgin queen from hive No. 68 was introduced. On July 3, the new queen was laying nicely and many eggs were present.

On July 26, 20 old workers from a frame of hive No. 81 were put into each of the 10 glass observation cases described on page 6, when 10 young workers just ready to emerge from a comb in the same hive were removed from their cells by means of uncapping the cells with a pair of forceps. Since a period of 21 days is required for the development of workers, counting from the time the eggs are laid to the time when the adult bees emerge, it is plain that these young workers were the daughters of the new queen, while all the other bees in the same hive were daughters of other queens. These young bees as usual had a faint sweetish odor and failed to give off any odor resembling the hive odor. Young bees removed from their cells by the method just described may be regarded practically devoid of the hive odor for the following reasons: (1) They emit a faint odor

which to the human nose fails to resemble the hive odor in the slightest degree; (2) they have not mixed with the other bees in the hive whereby they might have taken on the hive odor; and (3) it is not reasonable to think that a large amount of the hive odor penetrates the caps of the cells and adheres to the bodies of the bees. One of these 10 young workers was introduced into each of the 10 cases containing the old workers from the same hive. The old bees were more or less hostile to seven of the young ones, and received the other three without any signs of hostility.

The preceding experiments were repeated four times. In all five sets of experiments, the old bees were hostile to 38 young ones, while they showed no signs of hostility toward the other 12. These experiments were again repeated five times, but the old workers were taken from the alighting board of hive No. 81. Forty-nine young bees were received hostilely and no signs of hostility were shown toward the remaining one. Of the 100 young workers tested in the 10 sets of experiments, 87 were received hostilely, while 13 were received peacefully.

As a control for the foregoing experiments, 20 old workers from a frame of hive No. 38a were put into each of the 10 observation cases. A young worker removed from a sealed cell of a comb in hive No. 38b was introduced into each of the cases as usual. After repeating this set of experiments four times, the following data were obtained: Of the 50 young workers tested, two were received hostilely and 48 were received peacefully. As stated on page 21, all the bees whether young or old in hives Nos. 38a and 38b are supposedly offspring from the same queen and these experiments were not performed until the old workers in the two hives had become enemies to each other.

The experiments just preceding were repeated three times by using old workers from hive No. 23 and young workers removed from sealed cells of hives Nos. 2, 6 and 56. Of the 30 young workers tested, 22 were received hostilely and eight were received peacefully.

As described on page 15, half of a comb containing emerging workers was removed from hive No. 81 and was put into one of the wire-screen cages. Twenty of these young bees when four or five hours old were tested in the usual manner by introducing them into cases containing old workers from hive No. 49. Nineteen were received hostilely and one was received peacefully. When three or four days old, 30 of the same lot of young workers were introduced into cases containing old workers from their own hive (No. 81); all 30 young were received hostilely. It should be recalled that the

old bees and young ones used in this set of experiments were not sisters, and the lack of a hive odor being carried by the young ones is probably the chief reason why they were received hostilely, rather than to attribute the hostility to a strange family odor.

As already described on page 7, 50 workers from hive No. 38a were placed in each of wire-screen cases Nos. 1 to 3; 50 from hive No. 38b into each of wire-screen cases Nos. 4 to 6; 50 from hive No. 49 into each of wire-screen cases Nos. 7 and 8; and 50 from hive No. 29 into each of wire-screen cases Nos. 9 and 10. It will be remembered that all the workers in hives Nos. 38a and 38b were daughters of the same queen and that each new colony had formed a new hive odor before the workers were put into these cases. After a confinement of three days in the wire-screen cases the hive odor carried by the bees from their hives had disappeared, and as already stated each individual worker is constantly throwing off an odor which is slightly different from the odor emitted by any other worker, whether that worker be a sister or alien bee. When sister workers in cases Nos. 1 to 3 were mixed, no hostility was exhibited, because the individual odor of each sister possesses a family characteristic which is common to all the workers of the same queen and which is inherited from that queen. The family characteristic may be called the family odor, although it is only a part of the individual odor. The same interpretation may be used to explain why sisters in cases Nos. 4 to 6 did not attack each other when mixed; likewise why sisters after being confined three days in cases Nos. 1 to 6 did not attack each other when mixed. In these tests the two different hive odors had disappeared and it seems only reasonable to think that the bees recognized each other as friends by means of the family odor. The reason why sisters in cases Nos. 7 and 8, or those in cases Nos. 9 and 10, did not fight when mixed may possibly be attributed to the family odor. When alien workers from cases Nos. 9 and 10 were mixed with those in cases Nos. 1 to 6, or with those in cases Nos. 7 and 8, instead of much hostility being exhibited, the bees fought each other only lightly. This fact may be explained by the view that they recognized each other as strangers by means of the family odor, which in the daughters of one queen is only slightly different from that in the daughters of another queen.

5. QUEEN ODOR

On June 27 at 1 o'clock, 20 workers from a frame of hive No. 69 were put into each of the glass observation cases Nos. 1 and 2;

on this date this colony had emerging queens. A light colored queen that had just emerged was introduced into case No. 1 and a dark colored one was put into case No. 2; both queens were received peacefully and the workers fed them.

On July 1 at 1 o'clock, the above queens were transferred from cases Nos. 1 and 2 to cases Nos. 3 and 4 which contained workers from hive No. 70. When the light colored queen was introduced, a worker grabbed one of her feet, but soon let it loose; then she was fed and accepted peacefully. When the dark colored queen was introduced, the workers seized her legs and wings and held her for half an hour, after which they accepted her more or less peacefully.

On July 2 at 1 o'clock, 20 workers from a frame of hive No. 69 (the hive from which the queens were taken) were put into each of cases Nos. 1 and 2. A few moments later the light colored queen was introduced into case No. 1. At once the workers seized her legs and held her for three minutes, then they let her loose, cleaned and "caressed" her. The dark colored queen was put into case No. 2. The workers ran after her and one of them seized her leg, but did not hold it long, then they "caressed" her.

On July 3 at 1 o'clock, 20 workers from a frame of hive No. 28 were put into cases Nos. 3 and 4 as usual. The light colored queen was transferred from case No. 1 to case No. 3, and immediately upon being seized by a worker she killed the attacking bee, after which all the workers balled her, that is, clustered closely around her for five minutes; later they "caressed" her. The dark colored queen was transferred from case No. 2 to case No. 4, and the workers balled her for 25 minutes.

On July 5 at 9 o'clock, 20 workers from a frame of hive No. 50 were put into each of cases Nos. 1 and 2, and then the queens were transferred from cases Nos. 3 and 4 to these cases. Immediately after being introduced into the cases, the workers balled and tried to sting each queen, and consequently the dark colored queen was stung in the thorax, but she was not apparently injured. By 11 o'clock the queens had not yet been accepted; at this hour, 20 workers from a frame of hive No. 68 were put into each of cases Nos. 5 and 6, and the queens were then transferred from cases Nos. 1 and 2 to these cases; at once the queens were balled, and the light colored queen was crippled in one hind leg. On July 7 at 8 o'clock, the light colored queen was found dead in case No. 5.

On July 7 at 1 o'clock, another set of 20 workers from hive No. 68 was put into case No. 4, and on this date the bees in case No. 6

(sisters to those now in case No. 4) had accepted the dark colored queen. Immediately upon transferring the queen to case No. 4, a worker grabbed her and stung the under side of her thorax; she died immediately. To the writer this queen emitted a slightly stronger odor than did the light colored one.

Much more experimentation along this line would be required to prove conclusively that queens have individual and family odors and that they carry the hive odor on their bodies wherever they go, but since there are many evidences in practical bee keeping which support this view, we shall not dwell on it longer.

6. DRONE ODOR

Since the human nose is able to detect the very faint sweetish odor emitted by drones, the following experiments were performed to ascertain if this odor has any practical value to the drones themselves. Twenty middle-aged workers from a frame of hive No. 60 were put into each of the 10 glass observation cases. After the workers in these cases had become perfectly quiet, a drone from the same hive was introduced into each case; all 10 drones were received without any signs of hostility. This set of experiments was repeated nine times. In all 10 sets of experiments 100 drones were used, and each one of them was received without any signs of hostility.

These experiments were again repeated 10 times, but instead of using workers and drones from the same colony, the workers in each set of experiments were taken from a frame of a colony having drones, and the drones for the same set of experiments were taken from a different colony. Of 100 drones tested, 22 were attacked lightly and the workers attempted to attack the other 68.

The preceding experiments were again repeated 10 times, but the workers were taken from various droneless colonies. Of the 100 drones tested, each one was attacked quite forcibly.

There are three possibilities which may be suggested to explain why no hostility was exhibited toward a single drone of the 100 tested in the first 10 sets of experiments: (1) The drones probably carried the hive odor of their own hive, which might have rendered them immune to attacks; (2) the drone odor emitted by them might have also protected them; and (3) since they and the workers were offspring from the same queen, the drones might have had a family odor like that of their sisters. The workers might have regarded the family odor as a friendly token. The slight hostility noted in the second 10 sets of experiments might have been due to a combination

of a foreign hive odor and an alien family odor held in check by the drone odor. Since the workers used in these experiments were from colonies having drones, it is probably true that they were already accustomed to the drone odor, therefore this odor probably served as a check to prevent all the drones from being attacked considerably. Why all of the 100 drones tested in the third 10 sets of experiments were attacked considerably, might have been due to the combination of all three of the above enumerated possibilities. In these last experiments there was (1) a foreign hive odor, (2) a drone odor, to which the workers employed were not accustomed because their colonies were droneless, and (3) an alien family odor.

All the preceding experiments were performed in July, 1913, after the drone-killing time and when drones were comparatively few, but very similar results were obtained during the following May before the drone-killing time, and when drones were abundant. These experiments were repeated several times on July 15, 1914, and the results obtained were similar to those described. Other duties prevented the writer from continuing this experimentation in view of determining the relation between the odors produced and the factor causing the killing of drones. Those who maintain that bees are reflex machines, believe that a constant external stimulus is required during the drone-killing time, and reasoning from this point of view it might be possible that various factors cause the drone odor to change so that it might serve as the external stimulus to indicate to the workers that the drones must be killed.

According to the data obtained in all of the foregoing experiments, there is little evidence for the existence of a family odor in drones, but since it has already been shown that workers have a family odor, it is reasonable to think of drones also inheriting a family odor. These experiments do not prove conclusively that drones carry the hive odor, but since workers and queens carry the hive odor, it is logical to regard the drones in the same light. This possibility is further strengthened by the fact that all the combs, frames and even walls of the hive body are scented with the hive odor. After leaving small blocks of wood or queen cages in the hives for a few days and then removing them they give off the hive odor. According to the results obtained in the foregoing experiments, it may be inferred that drones when entering a strange hive are rarely molested if this hive contains several drones, but when drones enter a droneless colony they may be subjected to more or less hostility, although it is generally believed that drones go unmolested at all times and under all

conditions from hive to hive, except during the drone-killing time. It, therefore, seems that the drone odor serves as a check to reduce the hostility caused by a foreign hive odor which is carried on the bodies of the drones.

7. ODOR EMITTED BY GUARDS

In order to have a standard by which to judge the hostility exhibited when testing guards, fanners, middle-aged workers inside the hive, nurse bees, and pollen carriers all belonging to the same colony, 20 workers from the alighting board of a hive were put into each of the 10 glass observation cases. These workers included both guards and fanners taken promiscuously from the alighting board. Ten more guards and fanners taken promiscuously from another alighting board were introduced into the cases as usual. This set of experiments was repeated nine times. Of the 100 strange workers tested, each one was attacked fatally and most of them soon died, perhaps on account of being stung.

Twenty middle-aged workers from a frame of hive No. 79 were put into each of the 10 cases. A guard from the alighting board of the same hive was introduced into each case. This set of experiments was repeated nine times by using workers each time from a different hive. Of the 100 guards tested, 54 were received without any signs of hostility; the bees offered to attack two; nine were attacked very lightly; and 35 were attacked lightly.

8. ODOR EMITTED BY FANNERS

Twenty middle-aged workers from a frame of hive No. 81 were put into each of the 10 glass observation cases. A fanner from the alighting board of the same hive was introduced into each case. This set of experiments was repeated by using bees from two other hives. Of the 30 fanners tested, 14 were received without any signs of hostility; the bees offered to attack one; three were attacked very slightly; and 12 were attacked slightly.

9. ODOR EMITTED BY MIDDLE-AGED WORKERS INSIDE HIVE

Twenty guards from the alighting board of hive No. 48 were put into each of the 10 glass observation cases. A middle-aged worker from a frame of the same hive was introduced into each case. This set of experiments was repeated three times by using bees from three different hives. Of the 40 middle-aged bees tested from

inside the hive, 29 were received without signs of hostility; the guards offered to attack one; four were attacked very lightly; and six were attacked lightly.

These results explain why the workers in the top super of a tier of supers on a hive body are attacked by the guards of their hive should they escape from the super and try to pass into the hive through the entrance.

10. ODOR EMITTED BY NURSE BEES

Twenty middle-aged workers from a frame of hive No. 67 were put into each of the 10 glass observation cases, then a nurse bee from hive No. 23 was introduced into each case. Of the 10 nurse bees tested, the workers offered to attack two; four were attacked lightly; and four were attacked quite forcibly.

No experiments to test the odor emitted by wax generators could be devised, other than ones similar to those described just above, but the above experiments really deal with the hive odor rather than with the odor peculiar to nurse bees.

11. ODOR EMITTED BY POLLEN CARRIERS

To determine whether strange pollen carriers are accepted with less hostility than are strange workers without pollen, the following experiments were prosecuted. Twenty middle-aged workers from a frame of hive No. 73 were put into each of the 10 glass observation cases. A pollen carrier entering hive No. 81 was introduced into each of the 10 cases. Five of the 10 introduced pollen carriers were received peacefully and were fed, while the other five were attacked lightly. In three instances the bees in the cases ate the pollen on the legs of the pollen carriers. This set of experiments was repeated twice by using strange workers from various hives. Of the 20 pollen carriers tested, the bees showed no signs of hostility toward three; they attempted to attack seven; and 10 were attacked lightly. In five instances the pollen on the legs of the bees was eaten. These experiments were again repeated twice, but in these two sets strange workers from the entrances of various hives were put into the cases and the pollen carriers were taken from the entrances of other hives. Of the 20 pollen carriers tested, no signs of hostility were shown toward four; the workers attempted to attack five; 10 were attacked lightly; and one was attacked quite forcibly. The workers cleaned and ate the pollen from the legs of most of these pollen carriers.

To ascertain if workers from inside a hive would peacefully accept pollen carriers entering their hive, 20 workers from a frame of hive No. 7 were put into each of the observation cases. A pollen carrier about to enter the same hive was put into each case. This set of experiments was repeated with bees from hive No. 73. Of the 20 pollen carriers tested, 16 were accepted peacefully and four were attacked very lightly.

Twenty guards from hive No. 44 were put into each of three observation cases, then a pollen carrier about to enter the same hive was introduced into each case. One pollen carrier was attacked very lightly and two were attacked lightly.

Twenty pollen carriers about to enter hive No. 7 were put into each of five observation cases, then a guard from the same hive was introduced into each case. The pollen carriers showed no signs of hostility toward one guard; two were attacked very lightly; one was attacked quite forcibly; and one was killed. A few minutes later a guard from hive No. 29 was put into each case; four of the guards were attacked quite forcibly, and one was killed. While catching these pollen carriers the writer saw the guards on the alighting board attack and carry away a pollen carrier, and when the pollen carriers were put into the cases, three instances of fighting were seen among them. This hostility indicates that the attacked pollen carriers probably belonged to other hives, while the slight hostility of the workers used in the other experiments toward the pollen carriers seems to indicate one of two conditions as follows: (1) The workers and pollen carriers were probably hive mates, but the hive odor carried by the latter might have sufficiently disappeared in the field to cause the pollen carriers to be received with slight hostility, and (2) the workers and pollen carriers probably were not hive mates, but the hive odor carried by the latter might have so nearly disappeared that the workers could not distinguish them as strange bees.

It was planned to carry on similar experiments by using nectar carriers, but this was dropped for lack of time. In practical bee keeping we know that nectar carriers often enter strange hives without being molested, showing that the nectar they carry makes them immune to attacks, or that the hive odor carried by them has sufficiently disappeared to allow a peaceful reception.

12. EFFECT OF ODOR FROM BEE STINGS

To determine whether the odor from the stings of workers increases the hostility exhibited when strange workers are put together, 20

middle-aged workers from a frame of hive No. 67 were put into each of the 10 glass observation cases. The stings of 10 workers taken from the alighting board of another hive were extracted by letting the bees sting a meat rind. After having lost the stings these workers were active, though they did not have the energy and vitality of normal bees and when one of them was introduced into each case, it never offered to return the attack as does a normal bee. Each one was attacked less than is a normal bee under the same conditions. This difference in hostility is probably due to the abnormality caused by the extraction of the stings.

The effect of the odor from bee stings was tested in another way. Twenty middle-aged workers from a frame of hive No. 67 were put into each of eight cases. The extracted stings of 15 guards from hive No. 15 were placed in a small vial, and eight fanners from the alighting board of hive No. 67 were put into the vial containing the stings. After an interval of five minutes they were removed from the vial and one was introduced into each case; three fanners were attacked slightly, and the workers offered to attack the other five. As a control four guards from the alighting board of hive No. 67 were placed into an empty and odorless vial for five minutes. They were then removed and one was put into each of four cases; all four were attacked slightly. Another control was employed by using bees from hive No. 81. In this set of experiments middle-aged workers from a frame and fanners from the alighting board were used in the same manner as above described, but instead of using extracted stings of strange bees, stings of sister guards were used. The eight fanners were placed in the vial containing stings of sister guards. After an interval of five minutes they were removed and one was introduced into each case; six fanners were attacked slightly and the workers offered to attack the other two.

The foregoing results indicate that the odor from the poison which exudes from the sting does not increase the hostility exhibited when strange workers are put together, although we know from practical experience that when two or three bees sting a person's hand, other bees often attack the same hand immediately, indicating that the last bees were guided to the hand by means of the odor emitted from the poison of the first bees, but these two examples of hostility are not exactly parallel.

(a) EFFECTS OF ODORS FROM GLUE AND FINGERS

Twenty middle-aged workers from a frame of hive No. 7 were put into each of the 10 observation cases. The tip ends of the

abdomens of 10 bees from the alighting board of the same hive were covered with liquid glue. When the glue was dry one of these workers was introduced into each case; all 10 were attacked considerably. Sometimes the attacking bee grabbed the glued end of the abdomen.

After a short interval the writer rubbed his fingers along the dorsal sides of the thoraces and abdomens of 10 workers from hive No. 7 and then these bees were put into the cases with their hive mates; all 10 were attacked slightly.

(b) EFFECTS OF ODORS FROM CANDY AND HONEY

Many times when the observation cases contained hungry workers, like guards and fanners, strange workers that had been allowed to eat much candy or honey were introduced into the cases containing the hungry bees. In all such instances the hungry bees do not attack the others, but beg food of them and when food is not forthcoming they offer to attack the bees having food.

B. ODORS EMITTED BY OTHER INSECTS

Entomologists have observed that practically all insects have some means or other to produce odors, but comparatively few results dealing with the odors emitted have been published, and most of these appear as widely scattered notes. Under the above heading a brief discussion of the results of a few authors will be given, although under the following headings, which deal mostly with the morphology of the scent-producing organs, a more complete discussion of the literature will be presented.

The earlier entomologists observed the various means by which insects defend themselves, but they were usually ignorant concerning the origin of the various liquids secreted. For example, Burmeister (1836, p. 506) says:

Other insects secrete peculiar fluids, in which they partly envelope themselves and partly thereby secure themselves from the attacks of their enemies. The *Aphrophora spumaria* is one of these, which envelopes itself in a thick white frothy fluid, that comes out of the anus We find other coverings in the *Aphidæ* and tortoise-beetles, which envelope themselves with a white woolly or fibrous substance, the origin of which we are not yet acquainted with, but it appears likewise to be produced by a peculiar secretion of the skin. Other insects, as the *cantharides*, burying-beetles, carrion-beetles, carrion-flies, wasps, etc., emit upon being touched such a nauseous stench, that this must prevent every insectivorous bird from using them as food.

On page 509 Burmeister further says:

The generally known means of defense of the bomb-beetle (*Brachynus crepitans*) is of a peculiar description; it consists in its ejecting from its anus against its enemy a vapoury moisture accompanied by a slight sound, and which vapour has great resemblance to the gas of aquafortis.

We have before noticed some peculiar organs of secretion in several larvæ, as for instance, in that of *Pieris machaon*, which are projected at the approach of danger; they appear, in fact, to be glandular organs which partly secrete odours and partly liquids, for the purpose of chasing the enemy. . . . Among the beetles similar organs are found in the genera of *Cantharia* and *Malachius*, which in these are seated at the sides of the thoracic and ventral segments, and are likewise projected in time of danger.

Kirby and Spence (1823) remark that a fly, *Hemerobius perla*, and an ant, *Formica fætida*, emit an odor similar to that of human ordure. *Formica fuliginosa* imparts a strong odor to everything it touches. Many wild bees (*Melitta* and *Andrena*) are distinguished by their pungent and alliaceous odor. *Crabro flavum*, a wasp, emits a penetrating odor like that from ether.

Müller (1878 c-d) claims that odors may have been acquired by butterflies either for protection or to attract the opposite sex. In most cases protective odors appear to be equally strong in both sexes. Sexual odors may be divided into the following classes: (1) Those which attract or allure the opposite sex from a distance, and (2) those which excite the opposite sex during courtship. The male of *Didonis biblis* is able to emit as many as three distinct odors. When seized either sex of this butterfly protrudes a pair of protuberances from between the fourth and fifth abdominal terga; these protuberances emit a strong disagreeable odor. The male has a second pair of similar protuberances between the fifth and sixth terga; these emit an agreeable odor. The wings of the male emit a musky odor. In butterflies as a rule, Müller says that the scent-producing organs of males are located on the wings, but in a few genera (*Danais*, *Lycorea*, *Ituna*, *Morpho*, and *Didonis*) they are found on the abdomen, and in some Hesperidæ on the hind legs. Relative to moths these organs lie on the abdomen or legs, although not wanting on the wings.

Rye (1878) reports that a particular water beetle found in India emits a liquid, resembling walnut juice, which gives off a strong but not an unpleasant odor.

Lelièvre (1880) found that both sexes of *Thais polyxena* emit an odorous exhalation.

Dimmock (1882) says that most Staphylinidæ have a pair of "evaginable" organs, one on each side of the anus, which give off a disagreeable odor when protruded.

Pérez (1882) claims that each species of the bee, *Prosopis*, examined gives off a constant and characteristic odor which is unlike that emitted by any other species of the same genus.

Von Dalla Torre (1885) says that in many Zygænidæ each sex has a sac between the fourth and fifth abdominal segments, which exhales a very unpleasant odor. The males have, in addition, a pair of sacs between the fifth and sixth abdominal segments which emit an agreeable smell.

Howard (1889) says that the coccid, *Gossyparis ulmi*, gives off a pungent odor which is quite noticeable.

Haase, according to Plateau (1890), states that there are three types of scent-producing organs in Lepidoptera as follows: (1) The defensive ones produce an irritating and nauseating liquid; (2) the attractive ones are for bringing the males from a distance to the females; and (3) the seducing organs are possessed only by the males, and are found only in those species of which both sexes fly well. The odor emitted is aromatic and resembles that from vanilla.

Swale (1894) noticed that the staphylinid beetle, *Olophrum piceum*, is able to emit a quite disagreeable odor.

Hamm (1895), while collecting Lepidoptera, carried a bag, which a week previous had confined a female moth of *Bombyx quercus*. Several males of this species were attracted to the bag, and he attributes the cause of the attraction to the scent of the female still retained in the bag.

Keays (1895) placed a female of *Corycia taminata* in a box, and when it was removed, the box contained a filthy odor which was retained for hours thereafter.

Webster (1899) states that the odor emitted from the San José scale, *Aspidiotus perniciosus*, may be detected from a considerable distance.

Cockerell (1899) says that he has seen a male of *Margarodes hiemalis* "run over the ground until it detected a spot where a female was buried, and then dig down to the female. It must certainly have detected its mate by the sense of smell."

Johnson (1899) asserts that in the coccids, *Aspidiotus perniciosus* and *Chionaspis euonymi*, the odor emitted is perhaps for sexual purposes or for attracting other insects. In another scale insect, *Leca-*

nium nigrofasciatum, he regards the foul odor as a protection against the attacks of birds.

The odors emitted by certain social Hymenoptera have perhaps been studied more than those of all the other insects combined. For many years ants and bees have been regarded as having a colony odor (nest or hive odor). Jaeger (1876) was among the first to suggest that the colony odor is inherited, and speaking about bees Bethe (1898) called the hive odor "hive substance" and thought of it including both the family odor and colony odor. Bethe believes "that these family odors, common to all the members of one family, and differing slightly from those of other families of the same species play an important part in the life-history of the social hymenoptera. This family difference is due to the varying proportions of the constituent odors" (Geisler, 1907). Von Buttel-Reepen and the present writer have shown that the hive odor and family odor are two distinct odors and that only the family odor is inherited.

Fielde (1901) claims that a certain species of ants bears three distinct odors as follows: (1) A scent deposited by her feet, forming an individual trail, whereby she traces her own steps; (2) an "inherent" and inherited odor, manifested over her whole body, identical in quality for queens and workers of the same lineage, and a means for the recognition of blood relations; and (3) a nest odor, consisting of the commingled odors of all the members of the colony and used to distinguish their nest from those of aliens. Miss Fielde (1903) says that the odor of ants changes with their age, and that "A cause of feud between ants of the same species living in different communities is a difference of odor arising out of difference of age in the queens whose progeny constitutes the communities, and difference of age in the ants composing the community." She calls this odor the "progressive" odor and further (1904) claims that "Fear and hostility are excited in the ant by an ant-odor which she [the ant] has not individually encountered and found to be compatible with her comfort." The same author (1905) calls the family or "inherent" odor the "specific" odor which is transmitted by the mother ant to all her offspring of both sexes within the species. Miss Fielde claims that ants not only differentiate the innate odors peculiar to the species, sex, caste, and individual, but also the "incurred" odor of the nest and environment, and furthermore they can detect "progressive" odors, due to change of physiological condition with the age of the individual. She says that "as

worker ants advance in age their progressive odor intensifies or changes to such a degree that they may be said to attain a new odor every two or three months."

Wheeler (1913, p. 182) writing about the odors of ants says:

The specific odor may be readily detected even by the blunted human olfactories. Thus the odor of *Formica rufa* is pungent and ethereal, of *Hypoclinea gagates* and *maria* smoky, of *Acanthomyops* like the lemon geranium or oil of citronella, of the species of *Eciton* and some *Pheidole*, like mammalian excrement, of *Cremastogaster lineolata* fainter but equally unpleasant, of *Tapinoma* like rotten cocoa-nuts, etc. Undoubtedly ants are very quick to react to these various odors as well as to the "nest-aura," or odor which every colony derives from its immediate environment, brood, etc.

Concluding from the experiments on ants made by various observers, the family odor in these insects seems to play an important rôle by enabling the offspring of one queen to distinguish members of their family from those of alien families. Relative to ants the family odor is probably as important as is the nest odor, but in the honey-bee where certain social habits have been advanced to a higher degree, the family odor is of little or no use, because the hive odor has assumed such an important rôle in the recognition of the members of the same or of a different colony. Each colony of bees has its own hive odor and a small portion of which adheres to the body of each member of that colony, so that a bee is never entirely devoid of the hive odor. Should workers be forced to remain in the open air for at least three days, which is scarcely possible, they would lose their hive odor, and should they try to enter their own hive they would be attacked by their sister guards because the family odor emitted by them would not be a sufficient proof to the guards that they were friends; of course if the guards had also lost their hive odor, they would let these sisters enter unmolested.

Howlett (1915), endeavoring to lure the fruit fly, *Bactrocera* (*Dacus*), by using various chemicals, gives the following three probable explanations why the male flies are attracted so remarkably to methyl-eugenol and iso-eugenol: (1) The odors emitted from these substances may closely resemble the odors emitted by the females, and therefore they would serve as a sexual guide; (2) these odors may also resemble those emitted by certain plants, and in this case they would attract the females to the proper plants for breeding purposes; and (3) in a second case the odors would attract both sexes to these plants in order that the insects obtain suitable food.

C. SUMMARY OF ODORS EMITTED BY INSECTS¹

It is certain that a queen gives off an odor, and it seems reasonable that the odors from any two queens would be slightly different. All the offspring of the same queen seem to inherit a particular odor from her. This odor, called the family odor, perhaps plays little or no part in the lives of bees, for it is certainly masked by the other odors. Drones seem to emit an odor peculiar to their sex, but little can be said about it. It seems certain that each worker emits an individual odor which is different from that of any other worker. It is also probable that the wax generators and nurse bees emit odors slightly different from those of the field bees.

Of all the odors produced by bees, the hive odor is probably the most important. It seems to be the fundamental factor or principle upon which the social life of a colony of bees depends, and perhaps upon which the social habit was acquired; without it a colony of bees could not exist. The hive odor is composed chiefly of the individual odors from all the workers in a hive, and is supplemented by the odors from the queen, drones, combs, frames and walls of the hive, etc. From this definition it is easily understood why no two colonies have the same hive odor. The hive odor of a queenless colony is perhaps considerably different from that of a colony which has a queen. The absence of a queen odor in the hive odor probably explains why the workers in a queenless colony are irritable and never work normally. All the bees—workers, queen, and drones—in a colony carry the hive odor of that colony on their bodies among the hairs. This odor serves as a sign or mark by which all the occupants of a hive know one another. Since the queen and drones are "aristocrats," they seem to disregard the sign that has been thrust upon them, but whenever a queen enters the wrong hive, she soon "realizes" that she wears the wrong badge.

Worker bees returning to the hives from the field pass the guards unmolested, because they carry the proper sign, although the hive odor that they carry is fainter than when they left the hive, and it is also partially masked by the odors from the nectar and pollen carried by these bees.

Bees kept in the open air for three days lose all the hive odor carried on their bodies, but each bee still emits its individual odor. When a colony is divided the hive odor in each half soon changes

¹ A part of this summary has already been published in the *Amer. Bee Jour.*, July, 1916, pp. 232 and 233, and in the *Roots'* revised ABC and XYZ of Bee Culture, 1917, pp. 639 and 640.

so that by the end of the third day the original colony possesses a hive odor so different from that of the other half of the colony, that when the workers are removed from the two new colonies and are placed together in observation cases, they fight one another as though they had been separated all their lives.

While a foreign hive odor calls forth the fighting spirit in workers, the queen odor always seems pleasant to workers regardless of whether the queen belongs to their hive or to another hive. Even though the queen odor forms a part of the hive odor, it is probable that this odor to the workers stands out quite prominently from the hive odor. That workers do not miss their queen for some time after she has left the hive, indicates that her odor thoroughly permeates the hive odor and that whenever this odor grows faint the workers "know" that she is not among them.

There has been much speculation concerning the ruling spirit or power in a colony of bees. The present writer is inclined to believe that a normal hive odor serves such a purpose. The hive odor is a means of preserving the social life of the bees from without, and the queen odor which is a part of it insures continuation of the social life within. As already stated the workers "know" their hive-mates by the hive odor they carry. This odor insures harmony and a united defense when an enemy attacks the colony. The queen odor constantly informs the workers that their queen is present. Even though she does not rule, her presence means everything to the bees in perpetuating the colony. Thus by obeying the stimuli of the hive odor and queen odor, and being guided by instinct, a colony of bees perhaps could not want a better ruler.

All insects apparently emit odors, but only those of honey-bees and ants have been carefully studied; while the family odor among ants seems to play an important rôle, it is probably of little or no use among bees, because the hive odor has assumed such an important part in recognizing the members of the same or of a different colony. The progressive odor among ants is perhaps more highly developed than it is among bees, because the duties of ants are more varied than are those of bees and since slavery among ants is common.

SCENT-PRODUCING ORGANS OF INSECTS

In the preceding pages it is shown that insects, particularly ants and bees, recognize one another chiefly by means of odors, and since this is true they must have some means of producing these odors, because a hard substance like chitin is practically odorless to us and

certainly is not a good source of odors for insects. At first thought it might be argued that the blood of insects serves as a source for all odors, for the blood of different insects probably gives off slightly different odors, but it has never been shown that the blood of insects actually comes to the surface of the body; that the blood comes to the surface is more impossible for insects, owing to their chitinous covering, than it is for the higher animals. Of course devices for the blood to come to the surface might have been evolved, but after understanding the structure of the various types of scent-producing organs it will be seen that a much better specialization has been brought about, and instead of an insect pouring its vital fluid upon its external surface, gland cells have been evolved to extract the best constituents from the blood to serve as a source for odors; according to this specialization a smaller amount of liquid is required, because its volatility and ability to produce effective odors has been many times increased.

A. SCENT-PRODUCING ORGAN OF HONEY-BEE

It is reported that Nasonoff first described the morphology of the scent-producing organ of the honey-bee. His original work in Russian can not be had here, but according to Zoubareff (1883), Nasonoff did not describe the structure of this organ as seen by the present writer (1914), and he suggested that the gland cells of the organ produce perspiration. Sladen (1902) called this organ a "scent-producing" organ, but did nothing more than to describe the articular membrane between the fifth and sixth abdominal terga (propodeum not counted) of worker bees.

Externally this organ appears as a white transverse stripe near the distal end of the abdomen, but is visible externally only in worker bees that are fanning, however, it is present in all workers and queens, but has never been found in drones. The white stripe is the articular membrane and it is so folded that it forms a pouch which encircles about one-half of the abdomen and terminates on either side of the abdomen just above the articulation of the tergum and sternum. Just beneath the pouch lie many unicellular glands, each of which is connected with the bottom of the pouch by means of a chitinous tube through which the secretion passes into the pouch. The gland cells are modified hypodermal cells; they are granular and have conspicuous nuclei which contain many globular, refractive bodies. Each chitinous tube arises in the cell at the center of a clear area, the ampulla, which contains many radial streaks.

Judging from the morphology, we may reasonably conclude that the gland cells secrete a substance throughout their cytoplasm. This substance collects in the ampulla which serves as a reservoir, and from the ampulla the secretion passes through the chitinous tube to the exterior where it runs into the pouch. That the gland cells secrete an odorous substance is shown by the fact that when the articular membranes forming the pouches are excised, they appear wet and give off the characteristic bee odor, while the other articular membranes neither appear wet nor emit an odor. This view is further supported by the following: A virgin queen, emitting a very sweet and pleasant odor, was severed between the thorax and abdomen; when tested the thorax did not emit the sweet odor, while the abdomen did. The abdomen was then split into dorsal and ventral halves, and when tested only the dorsal half gave off the sweet odor. The dorsal half was next severed between the fourth and fifth terga, and in this case the portion containing the last two terga emitted a sweeter odor than did the other portion.

The groovelike indentations in the chitin forming the pouch may serve two purposes: (1) To give more flexibility to the chitin, and (2) to retain the volatile secretion and to help prevent a too rapid evaporation of it. So long as the abdomen is straight, the pouch is well protected and the liquid can not evaporate rapidly, but when the abdomen is considerably bent, the entire pouch is more or less exposed to the outside air.

The gland cells in old workers and queens are highly developed and are proportionately the same size, but the size of them increases little after the bees have emerged, and not until a few days later do they function in full capacity, judging from the fact that the odor emitted by workers just emerged gradually becomes more pronounced up to the fifth or sixth day.

The present writer failed to find gland cells connected with the articular membranes in the abdomens of drones, but they were not looked for elsewhere, and it is possible that some kind of a scent-producing organ may yet be found in drones. This assumption seems reasonable for sometimes when the abdomens of young drones are slightly squeezed, a very thin and whitish liquid may be seen on the abdominal articular membranes. At other times a clear liquid may be observed on the articular membranes between the fourth and fifth, and fifth and sixth abdominal terga; and it has already been stated that drones emit a faint sweetish odor.

B. SCENT-PRODUCING ORGANS OF OTHER INSECTS

A complete review of the literature pertaining to the scent-producing organs of insects has never been presented. Packard (1895, 1903) gives a fair review of this literature up to 1898, and Deegener (1912) briefly discusses the most important papers on this subject appearing between 1898 and 1912, but still the review is far from being complete. It is hoped that a good review of the work already done on this subject will aid and encourage future investigators who care to continue work along this line.

Deegener (1912), briefly reviewing the literature concerning the scent-producing organs of insects, divides them into the three following divisions: (1) Stink glands are found in Forficulidæ, Orthoptera, Hemiptera, Neuroptera, Lepidoptera, and Coleoptera, and reflex bleeding occurs in Coleoptera, Orthoptera, and Hymenoptera; (2) scent glands are found in Lepidoptera in general, and in other insects as Trichoptera, Coleoptera, and Apis; and (3) defense glands are separated from the stink glands only with difficulty.

Packard has divided these organs into repugnatorial and alluring organs, and a third class including those for recognition only might also be added. Since it is usually impossible to determine whether such organs are used primarily for defense, to allure, or for recognition, the present writer has called all of them scent-producing, for in perhaps most cases it is the odors produced that renders them of primary value; and he has not attempted any classification other than to divide them on the basis of their distribution, which is a convenient method for description. This review deals only with the literature pertaining to the scent-producing organs of imago insects, and does not include those papers dealing with these organs in larvæ.

I. UNICELLULAR GLANDS WIDELY DISTRIBUTED OVER THE BODY SURFACE OF BEETLES, ETC., AS SCENT-PRODUCING ORGANS

Aubé (1837) observed that a fetid and colorless fluid oozes from the surface of the elytra and thorax of beetles. This secretion is produced only when the insect is irritated and a moment after the irritation the insect is covered with many small drops of the liquid.

Burnett (1854) asserts that in some beetles the secretion is emitted from all parts of the body surface. In bugs the liquid is secreted by a single, yellow or red pyriform gland situated in the center of the metathorax, and opens between the posterior legs. In Formicidæ there is an anal gland which ejects a caustic and acrid

fluid; this gland is simple and is composed of one reservoir whose neck opens into a simple tube.

Hoffbauer (1892) who has made a special study of these glands in the elytra and pronotum of beetles, thinks that their secretion is probably for protection and he divides them into simple and compound glands. A compound gland is nothing more than a collection of the unicellular simple glands. The efferent canal may be either narrow, flaskshaped, or champagne-corklike, and it may or may not come to the surface at the base of a hair. Each gland cell may or may not possess a small reservoir.

Cuénot (1896b) asserts that when the beetles, *Melasma populi* and *M. tremula*, are irritated an odorous and opaline liquid may be seen on the elytra. This liquid is secreted by unicellular glands grouped in rosettes around a common efferent canal. These glands are found in the thickened portion of the elytron at the basal end. He regards the liquid secreted as an important means of defense.

Tower (1903) found simple and compound glands in beetles varying a great deal in complexity.

The simplest glands are single hypodermal cells modified for a glandular function, and are uniformly distributed over the entire body surface. In the elytron they arise in the pupal stage by the direct modification of one of the hypodermal cells of the wing lamella.

Instead of a gland opening at the bottom of a pit, it often opens at the top of a cone or stalk situated in a pit. In regard to the compound glands he says:

I suspect that these large glands of *Leptinotarsa decemlineata* are the cause of the peculiar odor that insect possesses which renders it obnoxious to most insectivorous animals. These glands persist in full functional activity as long as the beetle lives, although the hypodermis and unicellular glands will long since have degenerated.

Casper (1913) found hypodermal glands widely distributed over the entire body surface and legs of *Dytiscus marginalis*, and Lehr (1914), who resumed the search for hypodermal glands in other parts of the same insect, found them widely distributed in the wings and elytra.

The present writer (1916b) found unicellular glands widely distributed over the thorax, abdomen, legs, and elytra of the coccinellid beetle, *Epilachna borealis*. The wings contain none of these glands and the head with its appendages were not examined. Each gland cell lies beneath a pore in the chitin, and each pore possesses a spherical reservoir, from which runs an efferent canal to the exterior.

A chitinous tube passing through the inner portion of the pore connects the ampulla in the cell with the reservoir. The secretion is easily seen on the surface of the chitin; it has a bitter taste and emits a repugnant odor. For more details concerning the secretion and the structure of the gland cells see page 51.

Under the foregoing heading may be mentioned the wax glands, and the adhesive glands in the tarsi of various insects. While the primary function of these glands is certainly to produce wax and to enable insects to walk on smooth perpendicular surfaces, a secondary use is probably that of recognition; in regard to insects that follow their trails, for example ants, the secondary use seems quite plausible. For details concerning all these glands the reader is referred to Dreyling's paper (1906) on the wax glands of bees; to Packard (1903, p. 362) and others for information concerning the wax glands of Aphididæ and Coccidæ; to Packard (p. 111), Schröder (1912, pp. 10-13) and others for description of the unicellular glands in the feet of various insects.

2. CARUNCLES AS SCENT-PRODUCING ORGANS

(a) CARUNCLES OF A BEETLE

Laboulbène (1858) describes some caruncular structures in *Malachius bipustulatus* as being two pairs of beautifully red organs. They are remarkably large, soft, eversible, Y-shaped and are thrust out from the sides of the first and third thoracic segments. He was unable to detect an odor emitted from a single insect, but when several live insects had remained in a glass tube for a short time he detected a slight odor. When irritated these beetles evert the caruncles and direct them toward the enemy. He imagines that these organs emit an insensible odor to us, but a perceptible one to their enemies and that they are organs of defense.

Liege (1878) was the first to describe the anatomy of the caruncles of *Malachius*. He asserts that they are everted by blood pressure and are retracted by muscles. Since he failed to find glands in them, he refutes the view that Laboulbène advances, and he thinks that they aid in respiration.

(b) CARUNCLES OF A COCKROACH

Gerstaecker (1861) describes a peculiar organ in the Indian cockroach, *Corydia*. This organ in both sexes consists of two pairs of caruncular, evaginated saclike appendages which are located on the pleura of the first and second abdominal segments. He thinks that

they are perhaps similar in function to the caruncles described by Laboulbène.

Haase (1889a) says that the delicate chitin of these evaginated sacs is covered with finely netted ridges and that secreting tubules carry the secretion of the unicellular glands to the exterior through fine pores.

Klemensiewicz (1882) found oblong unicellular glands lying just beneath the hypodermis of the caruncles in the same species that the above two writers examined. The external end of each cell is attenuated and passes through the hypodermis and chitin. An efferent canal leads from the exterior opening and ends in the cell near the nucleus.

At this place might be mentioned the function of the cornicles of aphids. According to the latest researches, the aphids smear the secretion from these tubules on their enemies; the secretion thus has a protective function and perhaps its odors are also repellent (Wheeler, 1913, pp. 343-346).

3. PALPI OF A TRICHOPTERON AS SCENT-PRODUCING ORGANS

Müller (1887) says that each male of *Sericostoma personatum* that he held under his nose emitted a distinct odor resembling the odor from vanilla, and he thinks that this odor came from the wide maxillary palpi. Instead of the male palpus having four long joints as found in that of the female, it has but one joint and this is ladle-like with a flange on all sides. Inside the flange the surface of the ladlelike joint is covered with a tuft of fine hair. When males and females were kept together in a large vessel he noticed that a male placed himself against a female whereby the tuft of hair unfolded. He regards the hair and flange as a means for preventing a too rapid evaporation of the odoriferous secretion which he imagines comes from the interior of the joint, although he did not work out the anatomy of this organ.

4. GLANDS IN THORAX AS SCENT-PRODUCING ORGANS

(a) GLANDS IN PROTHORAX OF WALKING-STICKS

Scudder (1876) says that both sexes of *Anisomorpha buprestoides* are able to spurt a strong fluid or vapor from a pair of pores on the thorax; he considers this as a means of defense. Each pore lies at the bottom of a large deep pit on either side of the upper anterior surface of the prothorax. In *Diapheromera* the pores are smaller and do not occupy a position along the dorsum in which they are found in *Anisomorpha* and *Autolyca*. In *Autolyca pallidicornis* each of the

two glands is a straight, ribbonlike blind sac with stout walls. It extends from the posterior extremity of the mesothorax where it is broadly rounded to the anterior part of the prothorax where it is cylindrical. Here the secretion comes to the exterior through the slitlike aperture.

Haase (1889b) considers the preceding means of defense as an argument against the doctrine of Wallace and Poulton. According to this doctrine the non-edible species are not eaten, presumably because they have a glaring defensive color. Walking-sticks do not have such an appearance and yet are not eaten, for they defend themselves by use of stink glands.

Maynard (1889) also asserts that both sexes of *Anisomorpha buprestoides*, when irritated, are able to squirt two streams of a vaporous fluid 6 inches from the prothorax. When expelled the liquid is milky but almost instantly it changes to a vapor and has a pungent or peppery odor.

(b) GLANDS IN METATHORAX OF CERTAIN HEMIPTERA

Leidy (1847) describes the odoriferous glands of the electric light bug, *Belostoma*, as follows:

These consist of two moderately long cœcal tubes situated within the metathorax, beneath the other viscera, and extending into the anterior part of the abdomen. They are convoluted together in such a manner, that after one or two turns the closed extremity is brought close to the termination, both of which extremities are concealed by the passage over them of the ventral cord. They open externally between the coxæ of the posterior legs.

Leidy (1849) describes the odoriferous glands of Hemiptera as follows:

In Hemipterous insects these bodies are situated within the posterior part of the metathorax or anterior part of the abdomen, and consist of one or two, more or less long and convoluted cœca, which open exteriorly, usually between the coxæ of the middle and posterior legs.

Künckel (1866) asserts that the scent-producing organ of *Pentatomidæ* consists of a sac in the ventro-anterior portion of the abdomen. The sac opens to the exterior through two ostioles in the metathorax near the base of the hind pair of legs. The same author (1895) says that the Cimicidæ, Pentatomidæ, Coreidæ, and Lygæidæ are provided with two systems of scent-producing organs. The larvæ and nymphs have a tergo-abdominal system and the adults have a sternal metathoracic system like the one described above. Künckel (1886) claims that the repugnant odor of young bed bugs, *Cimex*

dectularius, comes from three invaginated sacs. These sacs lie just beneath the first three abdominal terga. Each opens to the exterior in the articular membrane by a pair of round apertures, one of which lies near and on either side of the median line. Gissler (1890) figures the scent-producing organ of the nymph of the common pine aphid, *Lachnus strobi*. Here an external opening of the gland lies on either side of the fifth abdominal tergum.

Mayer (1874) found a quite complicated scent organ in *Pyrrocoris apterus*. Close to the median line of the metathoracic sternum, a slit opens into a saclike cavity. Midway between the two ends of this cavity a flask-shaped vessel, the reservoir, leads off at right angles. The kidney-shaped gland lies between the reservoir and the integument; the collecting tube, whose free end is dichotomously forked, passes lengthwise through the center of the gland and unites with the neck of the flask-shaped reservoir. The walls of the gland are composed of oblong secreting cells. In the inner end of each cell a secreting tubule arises flasklike and runs into the collecting tube. The secretion is stored in the reservoir, and except when the insect is irritated is prevented from escaping into the saclike cavity by a valvelike apparatus. A sweet odor similar to that from chloroform is emitted from this organ.

(c) GLANDS IN THORAX OF BEETLES

Lacordaire (1838) reports that *Dytiscus* and *Gyrinus*, when picked up, emit through the articulations between the head and prothorax, between the latter and the mesothorax and between the metathorax and abdomen a milky and fetid liquid.

Plateau (1876) noticed that *Dytiscus* and *Acilius* emit, sometimes at the same moment, two different kinds of liquids. The one having a milky appearance issues from between the head and the tergite of the prothorax, the other is yellowish and exudes from between the meso- and metathorax. At each place where the liquid is emitted the secretory organ is composed of many unicellular glands which lie just beneath the hypodermis. The milky liquid is not venomous and thus can not be used in the capture of prey, and also it probably does not aid the sexes to find each other, because it does not have a pronounced odor. It can not be a means of defense because it is neither acid, nor strongly odorous and the quantity secreted is entirely too small for this purpose. The yellowish liquid perhaps forms an attractive coat on the surface of the body.

(d) GLANDS IN THORAX OF CERTAIN MOTHS

Fenn (1890) reports "that *Liparis salicis* has the power, when annoyed, of ejecting a pale greenish or yellowish fluid from (apparently) glands, situated on the thorax above the eyes." In *Arctia caia* there are two glands located just in front of the red "collar" of the thorax and they secrete drops of greenish fluid, which is acrid and is distasteful to birds.

Reid (1891) reports that acrid glands are possessed by a number of Lepidoptera besides the above named species, but he thinks that the secretion is to soften the cocoons so that the imagoes may more easily emerge, rather than primarily to serve as a protective fluid during the adult life.

5. ANDROCONIA OR SCENT SCALES OF MALE BUTTERFLIES AS SCENT-PRODUCING ORGANS

Deschamps (1835) was the first to study the scent scales of butterflies, although he credits the discovery of them to Baillif about 1825. Deschamps found them in 37 species, representing three genera. He called them plumules on account of their feathery tips and observed that they are much smaller than ordinary scales and are found only on the wings of insects.

In order that an intelligible description of the scent scales may be presented at the outset we shall quote Kellogg (1894) who says:

The androconia are found almost without exception on the upper side of the wings, and are more commonly met with on the forewings than on the hindwings. They are often found in certain limited spots, or in folds of the wings. This is usually the case among the Nymphalidæ, a familiar example being the pouch of the hindwings of *Danais archippus*. Among the Papilionidæ they are limited to folds on the wings, as those found along the inner margin of the hindwings of *Papilio*. In the Hesperidæ the androconia are found in costal folds or in the familiar discal spots or streaks. Among the Lycenidæ and Pieridæ they are most often scattered over the wing-surface being concealed in the general wing covering.

Mayer (1860) observed the scent scales while examining the "powder" on the wings of various butterflies.

Watson (1865a-b, 1868a-b) found the scent scales usually on the upper side of the wings of males. He found them in 507 species, representing 30 genera, belonging to six families. He asserts that these scales are so constant in different individuals of the same species as to be of valuable use in taxonomy. He thinks that they are to aid in respiration and also may be inflated with air and thus serve as a buoyancy.

Wonfor (1868, 1869) found these scales on the wings of males, belonging to several genera and he regards them as a sexual character.

McIntire (1871) reports having distinguished these scales from the ordinary ones.

Anthony (1872) also distinguished these scales from the other kind.

Müller (1877b) says that the male butterflies of the many species which he examined are distinguished from their respective females by the presence of these peculiar scales on the wings. The same author (1877c-d, 1878e) asserts that many male butterflies smell their respective females from an unbelievable distance. He thinks that an odor is emitted from these scales, and for this reason calls them "Duftschuppen." From the manner in which they are grouped he regards them as a good device for collecting the secreted liquid and for preventing a too rapid evaporation of it. Their generic differences are considerable and they vary somewhat in shape on the front and hind wings of the same species, but their specific differences as a whole are insignificant. He regards them as a secondary sexual character. Müller (1878f, 1879a) describes the scent scales found in the feltlike spots on the upper side of the male wings of three more genera.

Scudder (1877, 1881) asserts that these scales should be called androconia because only the males have them. He says:

These androconia are very capricious in their occurrence; a number of allied genera may possess them, while a single genus, as closely allied, may be quite destitute. . . . In the highest butterflies, they are long, slender and invariably feathered at the tip. . . . With the exception of the *Heliconii*, they may generally be distinguished from ordinary scales by the absence of any dentation at the tip. In the *Voracia*, they are fringed, and, with a single known exception, their extreme base is expanded into a sort of bulb; elsewhere, even in the other Pierids, they are not fringed, but have a smooth rounded edge. . . . In the Equites where also they have been supposed to be wanting they differ but little from the ordinary scales but are much smaller and more coarsely striate. In the *Urbiculæ*, where no one has hitherto recognized them, they present the greatest variety in the same individuals; in one group (*Hesperides*) there are hairlike androconia, and others which are exceedingly large and spindle-shaped. In the *Astyei*, besides hairlike and gigantic androconia, there are usually some which are spoon-shaped, with long handles.

Weismann (1878) predicts that an etherlike oil is secreted in the cells surrounding the bases of the scent scales. He imagines that this secretion passes through the scales to the exterior because the structure of the scales indicates a conducting device. The simplest type of these scales is hairlike and it is penetrated by a single axial

canal, which opens freely at the tip. Another type possesses many longitudinal canals whose external openings lie at the tip of the fringe that crowns the scale, or the surface of the scale is perforated by fine holes like a sieve. The odor that comes from a wing may be likened to that from a lemon, or a balm-tree blossom.

Aurivillius (1880a-b) calls these scales a secondary sexual character and based on their shape he has divided them into seven different types. This author found them in 110 species, representing seven families.

Von Dalla Torre (1885) says that the females of many lepidopterous insects give out odors perceptible to the males, and thereby induce copulation. It seems proven that by extending the ovipositor the female can cause the dissemination of the odor which attracts the male. In all male specimens of *Callidryas argante* examined, a musky odor was emitted from the scales when exposed on the wings. In *Prepona lartès* the odor is like that from a bat, and in *Dircenna xantho* it resembles that from vanilla. That we are unable to perceive a distinct odor from these scales in every species does not argue against the idea that the scales emit an odor, because the sense of smell is much more highly developed in the Lepidoptera than in man.

Haase (1886b, 1887, 1888a-b) made a special study of the scent scales of many families belonging to the Indo-Australian butterfliés. He found them usually grouped in brightly colored felt patches and considers them as a secondary sexual character. The odor emitted by several species is similar to that from vanilla. The scales lie so protected while at rest that an unnecessarily rapid evaporation is prevented.

Thomas (1893) says: "When scattered irregularly over the wing they are always underneath the large scales and therefore well protected." He was the first to prove by making sections through the wing that a secreting cell lies at the base of each scale. There is often a canal extending from the base to the tip of the scale where the secretion may find a direct outlet, or it may disappear in the spongy mass found at the end of these androconia.

Kellogg (1894) caught a male of *Pieris rapæ*, and after rubbing the upper surface of the front wing with the finger, he then smelled his finger and at once perceived a distinctly pleasing aromatic odor. This test therefore proves that the scales emit an odor.

Spuler (1895) shows that the dorsal surface of a scale is usually covered with many longitudinally parallel ridges while the ventral surface is smooth. There are also sometimes smaller transversely

parallel ridges. The chitinous layers of the two surfaces are held in place by many chitinous supports. The peduncle of the scale is hollow and its cavity is connected with those between the chitinous supports. According to his drawings the above characteristics hold good for both the ordinary scales and scent scales.

Leoni (1898) observed that *Pieris napi* and *Colias hyale* emit a delicious odor from the dorsal surface of the wings.

Köhler (1900) does not attribute a great significance to the scent scales, because while present on the wings of 78 species of *Lycæna*, they are wanting in 32 species of the same genus. He also says that the name androconia is not appropriate, because he has observed a few scent scales in a female belonging to this genus.

Guenther (1901) found that some of the scales on the wings are innervated while others are furnished with gland cells, however, he believes that all of the scales are probably innervated.

Illig (1902), who has prepared a comprehensive monograph on the morphology of the scent-producing organs of insects asserts that the peduncle of each scent scale arises from a flask-shaped socket in which the neck of the flask is quite wide. The inserted end of the peduncle is open and it extends through and slightly beyond the bottom of the flask. A large gland cell lies just beneath and against the base of the flask. Many chitinous ridges running parallel the full length of the scale lie on the dorsal surface, whereas the ventral surface is smooth. The two sides of the scale are firmly held in place by many chitinous supports. The interior of the peduncle and the cavities between the supports are filled with a netlike contents or matrix. In the feathered type the scales are tipped with hollow hairs while in the other types myriads of small pores are found between the parallel ridges. These pores run through the chitinous layer and communicate with the internal matrix. The secretion from the gland cell passes through the matrix in the peduncle and into the matrix which fills the cavities between the supports, then it slowly but gradually finds its way to the exterior, either through the hollow hairs at the tip or through the pores which are widely distributed over the dorsal surface of the scale.

Freiling (1909) has also carefully worked out the finer anatomy of various scent-producing organs of insects. The large gland cell at the base of each scent scale has a conspicuous nucleus, many vacuoles and some of them have a reservoir. From the reservoir runs a canal to the base of the peduncle where the secretion passes through definite canals through the matrix of the peduncle into the matrix

of the scale, then it infiltrates through the pores and forms a film over the entire dorsal surface of the scale. The bases of some of the scent scales are innervated.

6. GLANDS AT FEMORA-TIBIAL ARTICULATIONS OF BEETLES AND ANTS
AS SCENT-PRODUCING ORGANS

Lacordaire (1838) was one of the first investigators to describe the phenomenon of ejecting liquid from various parts of the body of certain insects. He says that when *Dytiscus* and *Gyrinus* are picked up, they emit through the articulations between the head, thorax, and abdomen a milky and fetid fluid. *Meloe* emits from the articulations of the legs a yellowish-orange liquid whose odor is not disagreeable. Coccinellidæ and Chrysomelidæ emit an analogous liquid at the same places, but it has a different odor and is quite strong.

Leydig (1859) was the first to make sections through the femoro-tibial articulations of *Timarcha*, *Coccinella*, and *Meloe*. He thinks that the discharged liquid is blood for the following seasons: (1) No gland cells nor glandular apparatus of any kind were recognized; (2) the discharged liquid and blood have the same color; and (3) the discharged liquid contains presumably blood cells. He admits that this view is not well founded because he could not find any openings in the articular membrane through which the blood could pass.

Magretti (1881) imagines that the discharged liquid from *Meloe* is secreted by gland cells in the legs.

Beauregard (1885) saw a layer of large hypodermal cells beneath the chitin in sections through the articulations of the legs of *Meloe*. He imagines that these large cells are gland cells.

De Bono (1889) believes that the discharged liquid from *Timarcha* is a glandular secretion.

Cuénot (1890) says that the discharged liquid from the legs of the meloid beetles, *Cantharis*, *Meloe*, *Mylabris*, and *Cerocoma*, is completely odorless, but it is slightly poisonous. He thinks that this liquid is blood, although he did not study sections passing through the articulations. The same author (1894) states that when one touches *Timarcha*, *Adimonia*, *Coccinella*, or *Meloe*, the beetles at once feign death. They fold the legs and antennæ under their bodies, fall to the ground and for a longer or shorter time assume a perfectly inactive attitude destined to deceive their enemies. At the moment when the insects roll on the ground, drops of a slightly viscid liquid are ejected from the mouths of *Timarcha* and *Adimonia*, but from the femoro-tibial articulations of the coccinellids and meloids. This

liquid is yellowish or reddish in color. The discharged liquid of *Coccinella* has a strong and very disagreeable odor, and that of *Timarcha* is odorless, but has a persistent and astringent taste. He proved by experiments that this liquid is for defense.

The ejection of a liquid from the articulations of the rudimentary wings of certain Orthoptera has been studied by Cuénot (1896a) and others. Cuénot (1896b) summarizes his investigations by saying that *Timarcha*, *Galeruca*, *Megalopus*, coccinellids, and meloids among the Coleoptera, and *Eugaster* and *Ephippiger* among the Orthoptera possess the phenomenon of reflex bleeding. When disturbed they feign death and eject drops of blood from the mouth, femoro-tibial articulations and from the articulations of the first pair of wings. In all these species the blood comprises toxic, caustic, or repulsive products. It is an important means of defense against lizards and batrachians.

Lutz (1895) asserts that in the Coccinellidæ, blood coming from the distal end of the femur issues through a slit on either side of the articular membrane which surrounds the chitinous rods (Selane) to which the extensors of the tibia are attached. The blood exudes by a forced contraction of the abdomen and by the flexors of the tibia, and it is a voluntary act. It is a means of defense because the blood is actually quite repulsive to insectivorous animals. In *Timarcha*, *Meloe*, etc., as in the coccinellids, the device of ejecting blood from the femoro-tibial articulations is to permit the blood to escape from the legs rather than through the mouth.

Packard (1895) states that many beetles, such as the oil beetles *Mcloe*, *Cantharis*, and *Lytta*, emit drops of blood from the femoro-tibial articulations as a means of defense. The cantharadine produced by these insects is formed in the blood and in the genital organs. It is so extremely caustic that scavenger insects feeding upon the dead bodies of these beetles leave untouched the parts containing cantharadine. Coccinellids are also protected by a yellow mucilaginous and disagreeable fluid which is emitted from the sides of the thorax.

Izquierdo (1896) says that liquids discharged by insects as a means of defense may be divided into three groups: (1) Those from organs which are furnished with glands. Such organs are found in all families of insects and their exits may be found in the thorax, abdomen, at the anus, or in the last portion of the intestine; (2) liquids which are discharged from the femoro-tibial articulations; and (3) liquids that are discharged from the mouth.

Porta (1903) says that the discharge of the secretion from *Coccinella*, *Timarcha*, and *Meloe* is caused by a reflex phenomenon brought about by any excitement. The liquid is secreted by a glandular follicle in the reticulum of connective tissue, which is situated in the wall of the middle intestine. The liquid has an acid reaction, and it is perhaps only a bile secretion. He gives three reasons why this liquid is not blood: (1) It is inadmissible that insects should constantly pass such an important fluid; (2) after a prolonged excitation the liquid ceases to exude; and (3) it has an acid reaction while we know that blood in all animals has an alkaline reaction. He fails to explain how this secretion reaches the exterior from where it is produced.

Berlese (1909) seems to think that the discharged liquid from *Meloe* is a mixture of blood and a secretion from hypodermal glands. In a diagram showing the anatomy of the leg at the femoro-tibial articulation, he figures a receptacle for containing the blood and shows how the blood is ejected through an aperture at this place in the leg. He also shows unicellular glands lying just beneath the hypodermis on both sides of the articulation. Each gland cell is almost spherical, has a conspicuous nucleus and a central vesicle, the ampulla, from which runs the efferent tube through the hypodermis and chitin to the exterior.

Schön (1911) found unicellular glands beneath the femoro-tibial articulations of *Camponotus* and the tibio-tarsal articulations of *Formica*.

The present writer (1916b) has examined the femoro-tibial articulations of the meloid beetles, *Cystodemus armatus* and *Epicauta pennsylvanica*, and of the coccinellid beetle, *Epilachna borealis*. No slits nor openings, except gland pores, were seen in the femoro-tibial articulations of these beetles. As already mentioned on page 39, hypodermal gland pores are widely distributed over the integument of *Epilachna borealis*. Usually one, but sometimes two pores, lie near the base of almost every hair. Besides lying near the bases of the hairs, the pores on the tarsi and around the femoro-tibial articulations lie in groups. Two groups are located at the extreme proximal end of the tibia and two at the distal end of the femur around the articular membrane. All four groups contain 100 pores as an average. The articular membrane contains about 400 pores of another type.

These beetles always appear wet, and the more they are irritated the wetter they become. The wet appearance is caused by a hypo-

dermal glandular secretion passing to the exterior through the pores. When irritated the beetles eject small drops of the amber-colored secretion from the femoro-tibial articulations through the four groups of pores near the articular membrane and those in the membrane. The discharge of the secretion is accomplished by putting the gland cells under a high blood pressure. This is made possible by a muscular contraction in the femur whereby the blood is forced into a specially devised chamber containing the gland cells which belong to the pores in and near the femoro-tibial articulation.

The gland cells are of two types: those with reservoirs are several times larger than those without reservoirs. The former are widely distributed throughout the entire insect, while the latter is found only under the articular membrane of the femoro-tibial articulation; in other respects the two types are alike. Each gland cell has an ampulla and a conducting tube which either runs from the ampulla to the reservoir in the chitin or from the ampulla to the surface of the articular membrane. An efferent tube leads from the reservoir to the surface of the chitin.

The glandular secretion is bitter and has an offensive odor. Its chief purpose is that of protection, but it probably also aids the beetles in recognizing the different individuals and sexes of the same species.

7. TUFTS OF HAIR ON TIBIÆ OF MALE MOTHS AS SCENT-PRODUCING ORGANS

Swinton (1877) observed tufts of hair on the tibiæ of the second pair of legs in various genera of Noctuidæ; on the tibiæ of the third pair of legs in various genera of Geometridæ, and on the tibiæ and first tarsal joint of the Deltoids. An odor is emitted from each of these tufts of hair.

Bertkau (1879a-b) found that the tarsi of the third pair of legs in the males of *Hepialus hecta* are completely aborted. The tibiæ are completely filled with elongated glands which open into pores in the chitin. From each pore arises a long scalelike hair. These hairs form a tuft on the inner side of the tibia and project slightly beyond the distal end of this segment. The same author (1882a) made sections through the tibiæ of *Hepialus hecta* and found large gland cells which are slightly club-shaped and reach entirely across the leg. Their nuclei lie in the broader ends of the cells while the narrower ends extend into the pores and communicate with the club-shaped hairs, which are firmly fastened in the pores by semicircular plates. The secretion of these unicellular glands is a volatile oil

which runs into the hairs. The oil infiltrates through the upper surface of the hairs and may often be noticed as minute yellowish-green drops. The odor emitted is aromatic and quite noticeable.

Müller (1879b) found a scent-producing organ on the inner side of the tibia of the third pair of legs in the males of *Pantherodes pardalaria*. The tuft of long hair lies in a groove and may be spread out fanlike. The same author (1879c) describes a similar organ on the tibia of a small species of *Erebidea*.

Bailey (1882) noticed fan-shaped brushes of hair on the legs of all the males of *Catocala* examined. He thinks that they may be aphrodisiac in function.

Barret (1882, 1892) detected an odor in the males of *Hepialus hectus*, which he thinks is emitted by the aborted hind legs. It is similar to the odor from ripe pineapples and it seems to attract the females. In every fresh male examined of *H. humuli* an odor was perceived, but in old ones no odor was detected. The same author (1886), while watching some males and females of *Hepialus hectus*, saw the females fly toward and against the males and he thinks that they were attracted by the odor from the males.

Edwards (1882) reports that he has seen these tufts of hair in the males of *Parthenos nubilis*, *Catocala desperata*, and *C. amatrix*.

Kirby (1882) reports that he noticed fanlike tufts of hair on the front legs of *Catocala fraxini*.

Johnson (1891), while watching a male and female of *Hepialus lupulinus* pairing in the air, thought without the slightest doubt that the female throws off a faint odor and that the vibration of the wings assists in diffusing it.

Deegener (1902) says that the tibiae of the third pair of legs in the males of *Hepialus hectus* are greatly swollen. They are club-shaped with the distal end the broader. The interior of the tibia is filled with large gland cells which stand at right angles to the pore field; between the gland cells are spaces filled with blood. A spatula-shaped hair, arising from the bottom of each pore, has longitudinally parallel ridges on the surface similar to those on the upper surface of the scales of butterfly wings. Between the upper and lower chitinous walls of a hair are canals to convey the liquid secreted by the gland cells. The same author (1905) describes a similar organ in the males of *Phassus schamyl*. Instead of the hairs in this species being spatula-shaped, they are usually scalelike with the distal end divided into two or three lobes. They have both the longitudinally and transversely parallel ridges. It may be assumed that the liquid secreted by each large gland cell passes through the pore into the

cavity of the scale which is filled with a granular matrix and then it infiltrates to the exterior through pores that are closed with very thin chitin. It may also be assumed that some of the secretion passes out of the pore around the base of the scale and then runs down the surface of the scale between the ridges. He thinks, therefore, that the scales are a means of spreading the liquid over a large area for quick evaporation.

Illig (1902) describes the scent-producing organs in the males of *Syrichthus malvæ* as fan-shaped tufts of long and slender hairs which lie on the proximal ends of the tibiæ of the hind legs. Muscle fibers are attached to the bases of these hairs to move them and a large gland cell lies at the base of each hair. Since the hairs do not open at their tips, the secretion evidently comes to the exterior through the pores around the bases of the hairs; but on the surface of the spatula-shaped hairs of *Hepialus hecta* he thinks that he saw fine pores through which the secretion probably issues. In *Pechipogon barbalis* the scent-producing organ consists of three tufts of hair on the front legs. The largest tuft lies at the distal end of the femur; one of the smaller ones midway between the ends of the tibia, and the other small tuft at the distal end of the tibia. The morphology of these three tufts and of their unicellular glands is very similar to that of *Syrichthus malvæ*.

8. PAIR OF LATERAL TUFTS OF HAIR AT ANTERIOR END OF ABDOMEN OF MALE MOTHS AS SCENT-PRODUCING ORGANS

Stefanelli (1870) says that only the males of *Sphinx convolvuli* emit an odor. The odor is strong but agreeable, resembling amber or musk. It comes from two lateral grooves on the first abdominal segment. The openings of the grooves are guarded by bunches of yellowish hair.

Tozzetti (1870) describes the scent-producing organ of the same species as follows: It consists of a pair of deep grooves, each one of which lies in the pleura of the first and second abdominal segments on either side. The groove is filled with long, slender, scalelike hairs. Each hair has a peculiar ringlike base whose lowermost portion extends into a long process which is inserted into a chitinous socket. Beneath the socket lies a unicellular gland containing a large nucleus.

Swinton (1877) saw this organ in *Acidalia remutata* and during copulation he observed that it expands. He also noticed it in *Acherontia satanas*; here it may be expanded into a stellate shape and a pungent odor of jessamine is emitted.

Müller (1878a-b) ascertained that the strong musky odor of a certain Brazilian sphinx moth comes from the organ described above.

Arnhart (1879) found a similar organ in *Acherontia atropos*.

Fügner (1880) saw the same organ in *Sphinx ligustri*. The odor emitted is musklike.

Von Reichenau (1880a-b) first described this organ in *Sphinx ligustri*. He says that a muscle is attached to the base of the hairs so that they may be expanded. Each hair is hollow and is filled with a secretion emitting a musky odor.

Hall (1883) noticed that *Acherontia atropos* emits a musky odor when the thorax is compressed.

Bertkau (1884, 1887) describes this type of organ as a shallow pocket, lined with hairs, in the pleura of the first and second abdominal segments. The slit-shaped opening of this longitudinal pocket is securely closed by hairs and it lies near the posterior edge of the pleuron of the second segment. Muscle fibers are present at the bases of the hairs and at the bottom of the pocket. The chitin is perforated by many fine pores, and from each pore runs a secreting tubule to a unicellular gland which is a modified hypodermal cell.

Haase (1884, 1886a) calls this type of organ in *Acherontia* a secondary sexual character because it is found only in the males. The hairs serve chiefly to spread the volatile oil which issues from the pores at the bottom of the pocket. During a forced expiration the hairs spread out raylike and thus greatly increase the available surface to assure a quicker evaporation of the oil.

Pollack (1887) observed similar scent-producing organs in *Hadena atriplicis* and *H. litargyria*.

Illig (1902) considers this organ in *Acherontia atropos* and *Sphinx ligustri* as a bunch of hair lying in a longitudinal groove, located as already stated. A large unicellular gland is connected with the base of each hair. Since the surface of the hair has longitudinal ridges and because the chitin between these ridges at times appears porous, it may be assumed that the secretion infiltrates through the apparent pores.

9. VARIOUS STRUCTURES AT VENTRO-POSTERIOR END OF ABDOMEN OF CERTAIN LEPIDOPTERA AS SCENT-PRODUCING ORGANS

(a) INVAGINATED SACS, TUFTS OF HAIR AND SCENT GROOVE OF CERTAIN MOTHS

Morrison (1874) saw two long, pale-yellow and hairy appendages projecting from under the extreme end of the abdomen of a male *Leucarctia acreæ*.

Stretch, Grote and Weed (1883) report having seen these appendages in the same species. Weed also saw them in *Pyrrharcia isabella* and pronounces them scent-producing organs.

Smith (1886) also describes these appendages of *Leucarcia acreæ*. They project from a narrow opening between the seventh and eighth sterna, and when not protruded they form two invaginated sacs. They are lined with hairs and are united at the base where they are attached to the integument. When protruded the hairs are on the outside of the evaginated sacs. In *Pyrrharcia isabella* these organs are four snow-white tufts of hair and in both species an intense odor, somewhat like that of laudanum, is emitted when the sacs are evaginated.

Freiling (1909) asserts that the abdominal scent-producing organ in the female of *Taumatopoca pinivora* is a large paired tuft of hair on both sides and above the anus. In the female of *Stilpnotia salicis* this organ is also a paired scent tuft. In the female of *Orgyia antiqua* it is a scent groove between the eighth and ninth segments just above the anus; here the articular chitin is very thin and it is probably an elastic membrane. Under a high magnification he saw a small quantity of secretion on this membrane. The gland cells are modified hypodermal cells and they lie in groups like several bunches of grapes with their stems attached to a common base. The interior of each bunch is greatly vacuolated and a string of vacuoles extends into each cell. He thinks that the secretion passes from the individual cells through the center of the bunch to the thin membrane where it passes to the outside by infiltration, although he saw no pores in this chitinous membrane. This organ in the female of *Bombyx mori* consists of the "Sacculi laterales," so called by Techomirow, although he did not understand their function. Freiling considers these the most complete and most highly developed scent-producing organ found in any female lepidopteron. This organ is a pair of invaginated and greatly folded sacs; each sac lies on either side of the abdomen, and both of them unite and open to the exterior by a long groove between the eighth and ninth segments. The layer facing the lumen of the invaginated sac is a thin and soft chitinous membrane, and it is thickly studded with small prickles. The layer of the sac facing the body cavity of the abdomen is composed of a one-celled layer of unicellular glands which are greatly vacuolated. He thinks that the secretion from the glands infiltrates through the thin chitin to the exterior. These sacs are evaginated by blood pressure and are retracted by muscles. He proved experimentally that the females

have a powerfully attractive force of some kind which causes the males to congregate around them, although he was never able to detect any odor coming from these sacs. With a piece of filter paper he drew some of the secretion from the outer surface of the evaginated sacs and then placed the paper in front of a freshly emerged male. The same reactions were obtained as when a male had been given access to a female in a box; at once the male threw himself upon the paper as if it were a female. While experimenting with silkworm moths, Kellogg (1907) obtained similar results and he says: "If the cut-out scent-glands are put by the side of and but a little apart from the female from which they are taken, the males always neglect the nearby live female and go directly to the scent-glands," and try to copulate with them.

(b) STYLED KNOBS AND INVAGINATED SACS OF CERTAIN BUTTERFLIES

Müller (1877a) regards a pair of small styled knobs, found only in the females of maracujá butterflies, as a scent-producing organ. In shape they are similar to the halteres of flies and lie on the posterior edge of the abdominal penultimate segment. The knobbed portion of the organ, which he thinks secretes a fluid, is covered with scales.

Illig (1902) says that the scent-producing organ in the male of *Danaïx pexippus* and *Euplœa* consists of two large chitinous, invaginated sacs, one of which lies on either side of the abdomen and opens to the exterior by a wide aperture between the seventh and eighth sterna. Scalelike hairs are attached to only the anterior portion of these sacs and a gland cell is found at the base of each hair. The secretion probably finds its way to the exterior through the socket around the base of the hair. This organ is evaginated by blood pressure and retracted by muscles.

Freiling (1909) says that in the female of *Gonopteryx rhamni* this organ is an invaginated sac lined with scalelike hairs, opening between the seventh and eighth sterna. In the female of *Euplœa asela* the organ consists of a circle of scalelike hairs on the eighth segment around the anus and of a pair of invaginated sacs lined with hairs. These sacs open to the exterior between the seventh and eighth sterna. In the males of *Euplœa asela* and *Danaïx septentrionales* this organ is a pair of invaginated sacs, one of which lies on either side of the abdomen with its external opening at one side of the anus between the seventh and eighth segments. Most of the scent hairs are attached to the anterior portion of the sac and when the sac is

evaginated and the tuft of hair is expanded, this organ greatly resembles a cylindrical fan whose contents are turned inside out to form the circular part of the fan. Freiling asserts that scent hairs are more common than scent scales in abdominal scent-producing organs. A few of these hairs are innervated and vacuoles seem to be always absent in the large gland cells at the bases of the hairs, but a secreting tubule is invariably present. The scent hairs may have parallel ridges with myriads of fine pores in the chitin between the ridges, or they may have many stubby, thornlike projections, each of which is pierced by a small canal through which the secretion passes to the exterior. The scent hairs are filled with a matrix substance.

IO. ANAL GLANDS AS SCENT-PRODUCING ORGANS

(a) ANAL GLANDS OF COCKROACHES

Bordas (1901) describes a voluminous organ in the posterior end of the abdomens of males belonging to *Periplaneta orientalis* and *P. americana*. This organ is a slender sac with a series of dichotomously branched tubes running into its anterior end. The posterior, or narrower end of the sac opens to the exterior by an oval aperture in a chitinous projection under the penis. The gland itself lies in the ventral portion of the abdominal cavity at the right, and all of its tubes are surrounded their full length by a layer of unicellular glands. A cross section of one of these tubes shows three layers in its wall as follows: (1) The outer layer is a thin membrane; (2) the middle one is a layer of trapezoidal gland cells; and (3) the inner one is the chitinous lining of the tube. Each gland cell has a large nucleus and a vesicle from which runs a filamentous, secreting tubule to the chitinous canal, the collecting tube. This gland secretes a volatile, strong and nauseating liquid, sometimes acrid and alliaceous, recalling the odor of a mouse or that from old cheese in decomposition; it secretes continuously but in time of danger its action is accelerated.

Harrison (1906) describes a supposedly new organ in *Periplaneta orientalis*. This glandular organ lies on the ventral side in the sixth abdominal segment and opens to the exterior between the sixth and seventh sterna. From the external opening the organ extends upward and forward as two distinct lobes.

(b) ANAL GLANDS OF BEETLES

Dufour (1811) first described the anal gland of the bombardier beetle, *Brachinus displosor*. This gland is paired and one half of it

lies on either side of the abdominal cavity. Each half is divided into the three following parts: (1) The spherical reservoir lies under the last dorsal segment of the abdomen just under the rectum and opens at the side of the anus; (2) the preparator is a large saclike organ lying just behind the reservoir; and (3) the long threadlike duct is the anterior continuation of the preparator.

He found an organ similar to the preparator in several other carabids and also in *Blaps*. These beetles, when excited, discharge an acrid and caustic liquid through the two apertures near the anus. Dufour (1826) remarks that the Dytiscidæ are able to discharge a colorless and disagreeable fluid from the anus. Silphidæ emit from both the mouth and vent a fetid liquid having an ammoniacal odor; the members of this family have a single anal gland.

Meckel (1846) says that the reservoir of the anal gland in *Dytiscus* contains a yellowish-white emulsion. The secretion has a rancid odor, an acid reaction, and a defensive function. The gland cells are comparatively large, and in the collecting tubes leading from these cells may be seen drops of the secretion. In *Carabus auratus*, *C. coucellatus*, and *Chlænium vestitus* the gland consists of grapelike bunches; in *Chlænium velutinus* of three short, broad sacs which empty into a canal (the efferent canal) leading to the exterior; in *Aptinus* the gland is five lobed; in *Brachinus* it consists of convolutions of blind sacs which unite at a common point with the efferent canal; in *Bombylius* and the water beetles the gland is a long, convoluted, and closed vessel.

Karsten (1848) remarks that this organ in *Brachinus complanatus* is paired. Either external opening lies above and to one side of the anus, and the posterior end of either kidney-shaped reservoir communicates with its respective external opening. From the anterior end of the reservoir runs a collecting tube which soon divided into twelve glandular tubes, each one of which has a central canal, and its peripheral end is free. The gland cells are spindle-shaped and stand perpendicularly to the central canal, which is filled with a greenish fluid.

Candèze (1874) reports that certain carabid beetles throw a burning and extremely fetid liquid on their enemies.

Gissler (1879) remarks that the repugnatorial gland of *Eleodes gigantea* and *E. dentipes* is paired. The secretion has an intensely penetrating odor and causes the eyes to shed tears. When irritated, these beetles stand on their first two pairs of legs with the abdomen high in the air and the liquid is thrown right and left.

De Rougemont (1879) describes the organ causing the explosions in *Brachinus crepitans* as a paired structure in which the collecting tube is a double canal. Its inner tube which is filled with air is arranged spirally inside the cylindrical outer tube. The anterior end of this double tube is divided into two branches which are also filled with air and the walls of these branches are composed of gland cells. A brown liquid, butyric acid, is found in the reservoir. The author thinks that this acid is passive as long as it remains in the reservoir, but when it is discharged to the outside by the force of the condensed gas inside the collecting tube, it becomes active and produces a strong odor.

Bertkau (1882b) describes the anal gland of both sexes of the click beetle, *Tacon murinus*, as a saclike cavity which is protruded when its secretion is discharged; the sac is retracted by a muscle. The spherical gland cells lie in the walls of this large sac. The long, fine, and entwined secreting tubules arise beside the nuclei of the gland cells and several of them run into the sac at the same point. Each tubule begins as a faint swelling in the cytoplasm of the unicellular gland, but he noticed no vesicle. The lower portion of the sac serves as a reservoir where the secretion is collected.

Williston (1884) reports that when either sex of *Eleodes longicollis* is disturbed, it discharges a pungent and vile smelling fluid from the anal glands.

Townsend (1886) placed some carabids, *Calathus gregarius*, in a bottle, and subsequently the bottle was filled with white smoke, which he concludes was brought about by the anal glands.

Loman (1887) discovered that a beetle, *Cerapteris maculatus*, from Java causes loud explosions when the secretion of its anal glands is discharged. He found that this secretion, which is to guard off enemies, contains free iodine.

Gilson (1889a-b) describes the anal glands of *Blaps mortisaga* as two cylinders which unite to form a short tube. This tube opens at the lower part of the last intersegmental space of the abdomen. Each cylinder is a sac whose walls are covered with a large number of whitish lobes. While the sac is a reservoir, each lobe is a collection of unicellular glands. He says that these cells constitute the most complete type of unicellular glands and one of the most complicated forms of all cells. Besides having a conspicuous nucleus, each gland cell has a radiating vesicle, a central ampulla, a secreting tubule and a sheath around the tubule. The cytoplasm of the cell contains radial streaks which radiate toward the vesicle. The club-

shaped ampulla arises at the center of the vesicle and runs to the outside of the vesicle where it continues as the secreting tubule, which winds about considerably, passing through the lumen of the lobe in order to open into the reservoir. The sheath of the tubule arises inside the cell but encloses the tubule for only a short distance. The secretion is an odorous oil in which swims a considerable number of crystalline and yellow needles.

Leydig (1890) says that the glands of *Anchomenus* deviate from those of *Brachinus* in that they do not consist of long pouches, but of round sacs similar to those in carabids. He is not certain how the secreting tubules arise in the cells; Leydig in 1859 was the first to describe the finer structure of these unicellular glands.

Pórtér (1895) experimented with eight individuals of *Eriopis convexa* (Coccinellidæ), one of *Chelymophra varians* (Chrysomelidæ) and five of *Læmosthenes complanatus* (Carabidæ). In all of these he concludes that the liquid emitted by or near (por) the anus is not the product of a secretion, but it is blood because this liquid and some blood taken directly from the dorsal blood vessel both contain corpuscles (leucocytes) of the same form, same dimensions, same coloration, similar micro-chemical reactions and the same amœboid movements.

Bordas (1898) describes the anal glands of Dytiscidæ as a very voluminous structure. They are paired and consist of two white, intestinellike tubes, wound into an ovoid mass and located in the last abdominal segments. The gland consists of the three following layers: (1) The outer one is a thin peritoneal membrane; (2) the middle one consists of muscular fibers; and (3) the inner one lining the lumen of the collecting tube is an epithelial layer composed of rectangular secreting cells. The collecting tube runs into a reservoir whose muscular layer is more powerful than that in the gland just mentioned. When excited, the insect discharges a yellowish liquid into the surrounding water, making a slight brownish cloud by the aid of which the insect may easily escape its enemy. The same author (1899a-b) says that when *Brachinus* is disturbed an acrid liquid is discharged which produces a crepitation; the liquid at once changes into a little cloud of pungent and corrosive vapors and the detonations may be repeated 10, 15, or 20 times in succession. He has studied these glands in several genera of Carabidæ and in each species he found grapelike unicellular glands, secreting tubules, a collecting tube, a reservoir, and an efferent canal leading into the cloaca. Bordas (1899c) asserts that 24 genera and 56 species of Coleoptera, repre-

senting the families and subfamilies—Cicindelidæ, Carabinæ, Harpalinæ, Feroniinæ, Brachininæ, Dytiscidæ, Gyrinidæ, Staphylinidæ, and Silphidæ possesses anal glands. Bordas (1899d) says that the collections of gland cells may be oblong, grapelike, or may form a solid layer around the collecting tubes their full length. Each unicellular gland has a central nucleus and a vesicle which lies near the inner end of the cell from which runs a secreting tubule to the lumen of the collection of cells. The collecting tubes are usually filamentous and tortuous; the reservoir is ovoid, oblong, or kidney-shaped, and the efferent canal may be long or short.

Dierckx (1899a-e), whose descriptions and drawings of the anal glands are the most comprehensive of all the researches pertaining to these particular structures, calls them the pygidial glands, because their external openings are a pair of apertures on the pygidium or the last abdominal segment. He used many species of Carabidæ and Dytiscidæ. Each unicellular gland possesses besides a nucleus, a spherical, cylindrical, pyriform-shaped, or multilobed, radial vesicle which communicates with the lumen of the collection of cells by a filamentous, intravesicular tubule. Near the external opening of the efferent canal he discovered a new gland which he calls the "glande annexe." This structure is also composed of unicellular glands with magnificent radial vesicles. These cells are arranged around the efferent canal into which the secreting tubules empty just at the exit. The secretion of the anal gland is colorless, has a faint odor, and is very volatile. In Dytiscidæ the pygidial gland is double. Each half consists of a long intestinelike collecting tube which is surrounded by the unicellular glands, of an ovoid reservoir with feeble muscles, and of a short and tortuous efferent canal leading to the exterior. Each secreting cell has besides a large nucleus, from one to four vesicles which lie in a group. The secretion has an agreeable odor and judging from the anatomy of the reservoir a quick discharge is impossible, nevertheless an explosion brought about by this gland never occurs. In *Dytiscus* the defensive apparatus is the rectal pouch greatly enlarged by water charged with gas. When disturbed, the insect empties its rectal pouch whereby the excremental substances are blown against the enemy. He thinks that the anal glands of Dytiscidæ are to facilitate respiration.

Dierckx (1899f) asserts that the pygidial gland in *Staphylinus casareus* is paired. It seems to be a pair of invaginated sacs which are evaginated by blood pressure and retracted by muscles. The gland cells lie in the walls of the sacs and a secreting tubule runs from a

vesicle in each cell and empties its contents into the invaginated sac. The same author (1900) claims that among the carabid bombardiers, *Pheropsophus* holds the record for the complexity of its defensive organ. There are twelve collecting tubes which empty into the hilum of the kidney-shaped reservoir. The free end of each collecting tube is divided into about a dozen short glandular tubes, and the reservoir empties into a chitinous capsule whose walls are surrounded by the cells of the "glande annexe." The capsule empties into an efferent canal which runs to the exterior. Dierckx (1901) presented his second large paper concerning the pygidial glands of beetles. He has worked out the finer anatomy of various representatives belonging to the Carabidæ, Paussidæ, Cicindelidæ, and Staphylinidæ. In the various species examined the collecting tubes may vary in number from one to several for each reservoir. The gland proper may be a widening of the free end of the collecting tube, or a kidney-shaped mass containing the many ramifications of the free end of the collecting tube, or this free end may possess several short branches which are not massed together, or the gland cells may be arranged in bunches like grapes at the free end of the collecting tube. He found the "glandes annexes" in most of the species examined, and claims that they produce the yellow and clammy constituents in the substance secreted.

Francois (1899) claims that the pygidial gland of *Aptinus displosor*, a carabid belonging to Brachynini, is more complicated than that of *Brachinus*. In this species there are three collecting tubes for each reservoir, and the free end of each tube is terminated by four or five pairs of small groups of secreting cells, arranged grapelike. The reservoir runs into a chitinous capsule which opens to the exterior by an aperture under the exit of the cloaca. This gland has a special innervation.

Escherich (1899) concluding from the works of Dierckx, Bordas, and Francois about the pygidial glands, remarks that all beetles possessing these glands may be divided into two main groups: (1) Those in which the collecting tube is simple, *i. e.*, without an inner tube; the glands may be acinous or tubular; and (2) those in which the collecting tube is double, *i. e.*, with an inner chitinous tube.

Seidlitz (1899) reports a scent-producing organ in *Blaps*, *Glasunovia*, and *Dermestes*.

Brandes (1899) states that in certain beetles bunches of bristles are found on the head and thorax, and he thinks that these bristles form a bridge between the scent organs of other orders of insects and the anal glands of other beetles.

(c) ANAL GLANDS OF ANTS

Forel (1878) was able to find anal glands in only the workers and queens belonging to the subfamily Dolichoderidæ (a division of Formicidæ). He has found them in *Bothriomyrmex meridionalis*, *Tapinoma erraticum*, *T. nigerrimum*, *Liometopum* (?) *sericeum*, *Dolichoderus* (*Hypoclinea*) *attclaboides*, and *D. bispinosus*. The gland in each of these species is very similar to that of *Bothriomyrmex* which he describes in detail. Just above the anus lies a slit-shaped external opening which leads into the efferent canal of the paired gland. Both reservoirs, which occupy about half of the space at the posterior end of the abdominal cavity, run into the same efferent canal. At the outer side of each reservoir lie the unicellular glands, arranged grapelike. A large collecting tube runs from the bunch of cells and empties funnel-like into the base of the reservoir. Each spherical cell has a large nucleus containing many nucleoli. Wound around inside the cell he saw a chitinous secreting tubule surrounded by a transparent sheath; the tubule runs into the collecting tube. A protoplasmic sheath containing nuclei encloses the secreting tubule outside of the cell, and even the collecting tube is likewise enclosed. Tracheal branches run between the gland cells and seem to be closely connected with the secreting tubules. The reservoirs are well supplied with muscles and also with tracheal branches. Forel claims that most ants have a more or less strong and characteristic odor; the two species, *Lasius emarginatus* and *L. fuliginosus*, have different odors; in these the scent-producing organ lies in the mandibles (Oberkiefer) and metathorax.

II. INVAGINATED SACS AND POUCHES AT THE DORSO-POSTERIOR END OF ABDOMEN AS SCENT-PRODUCING ORGANS

(a) INVAGINATED SACS AND POUCHES OF CERTAIN ORTHOPTERA

Vossler (1890) describes this organ in the ear-wig, *Forficula auricularis*, as two pairs of lateral structures in the third and fourth abdominal terga. Each one of these consists of a reservoir having a narrow neck which opens to the exterior through a slit. Muscles are attached to the neck of the reservoir to open and close the slit. The walls of the reservoir are composed of unicellular glands, each of which besides having a nucleus has also a vacuolated area from which runs a secreting tubule into the reservoir. In the reservoir he found a yellowish or brownish liquid, which may be thrown from 5 to 10 centimeters from the insect.

Garman (1891) reports that the males of the cricket, *Hadenacrus subterraneus*, protrude a pair of white, fleshy appendages from slits between the ninth and tenth abdominal terga. He thinks that these appendages are protruded only during the period of sexual excitement.

Minchin (1888) describes a new organ in *Periplaneta orientalis*. This organ consists of a pair of shallow, lateral pouches near the median line in the articular membrane between the fifth and sixth abdominal terga. The pouches are covered with the fifth tergum, but connect with the exterior by a pair of slit-shaped openings. These pouches contain numerous, stiff and branched hairs, and just beneath the chitinous lining of the pouches lie unicellular glands which extend into the enlarged bases of the hairs. He thinks that probably the secretion from these cells runs into the hairs which serve as a means of diffusing the odor. The same author (1890) describes a second glandular organ in the same species. This organ consists of a pair of tubular ducts which lie just above the pouches of the first organ, and they open to the exterior through apertures near the slitlike openings of the pouches.

Krauss (1890) observed in the roach, *Aphlebia bivittata*, invaginations whose common exit may be seen on the seventh abdominal tergum. These invaginations are filled with hairs.

Oettinger (1906) describes the scent-producing organ in the roach *Phyllodromia germanica*, as two double pouches, one of which is located in the articular membrane between the fifth and sixth, and the other between the sixth and seventh abdominal terga. They are found only in the sexually matured males. Each pouch is a double invagination, being divided in the median line by a tonguelike partition, and muscles are attached to the walls of the pouches. When the muscles contract the lumen of the pouch is constricted whereby the secretion is forced to the exterior. Beneath the chitinous lining of the pouch lies an irregular layer of supporting cells. The layer next to the abdominal cavity is composed of long, cylindrical and extremely large gland cells, each of which has a reticular netlike contents and a conspicuous nucleus having several nucleoli. A secreting tubule arises near or even against the nucleus, pierces the contents of the cell and runs to the lumen of the pouch. The gland cells as usual are modified hypodermal cells. In *Periplaneta orientalis* the pouch is lined with hollow hairs into which the secreting tubules of the unicellular glands run. He thinks that these organs bear a close relation to the sexual behavior of these insects.

(b) INVAGINATED POUCH OF HONEY-BEE

Under this heading belongs the description of the scent-producing organ of the honey-bee, but since a brief review of it has already been given on pages 36 to 37, further remarks are unnecessary.

C. SUMMARY OF SCENT-PRODUCING ORGANS OF INSECTS

In the first part of this summary the scent-producing organs are grouped on the basis of their devices for disseminating the odors and for storing the secretion, while in the second part they are grouped according to the order of the insects being discussed.

A review of the literature shows that the substance produced by any scent-producing organ is secreted by unicellular glands which so far as known are modified hypodermal cells. On this point Gazagnaire (1886) remarks that glandular cells of hypodermal origin are widely distributed in insects. They secrete the various fluids exuding through the chitin, and since their histology is so similar it might be admitted that they have the same general structure. For description, scent-producing organs may be divided into five types based on their devices for disseminating the odor and for storing the secretion as follows: (1) No special device for disseminating the odor or storing the secretion; (2) gland cells associated with hairs and scales as a means of scattering the odor more effectively; (3) "evaginable" sacs lined with hairs connected with gland cells as a device for storing the secretion and distributing the odor; (4) articular membranes serving as pouches for storing and preventing a too rapid evaporation of the secretion; (5) specialized tubes and sacs acting as reservoirs for storing and discharging the secretion.

The first type is the simplest of all five types. It is best represented as unicellular glands uniformly distributed over the entire body surface as found in several beetles. In this type of scent-producing organ the secretion passes through the chitinous tubes to the exterior where it spreads over the surface of the chitin surrounding the exits of the tubes.

In regard to spreading the secretion over a wider area, the second type is much more highly developed than is the first type. This is accomplished in most cases by the secretion spreading over the surfaces of many large hairs arranged in tufts which may be expanded into a fan-shaped figure. In the second type the secretion from the gland cells passes into the hairs and scales and then spreads over their surfaces, whereby the odor from the secretion is more effectively disseminated.

In regard to storing the secretion in an "evaginable" sac, the third type is a little further advanced than the second type. The sacs are evaginated by blood pressure and retracted by muscles, and the odorous substance may be more or less retained in the invaginated sacs, but when the sacs are evaginated, like the fingers of a glove, all the odor escapes.

In regard to storing the secretion, the fourth type is more highly organized than any one of the preceding types. The scent-producing organ of the honey-bee belongs to this type, and it is one of the most highly developed organs of its kind. At this place might be mentioned some unicellular glands found in ants. In the petiole of the worker ant of *Myrmica rubra*, Janet (1898) found an invaginated chamber; at the bottom of the chamber may be seen the exits of the tubes which lead to a bunch of unicellular glands. He also found in the same ant two small groups of unicellular glands beneath the articular membrane between the ninth and tenth abdominal terga. These glands are also connected with tubes which run to the exterior. Both of these organs may possibly be scent-producing organs, and may be similar in function to that of the honey-bee.

Relative to storing and discharging the secretion as a means of defense, the fifth type is the most highly organized of all the five types of scent-producing organs. It is thus seen that there is a wide variation in organization between the lowest type and the highest type. All of those organs belonging to the first four types are used in all probability for alluring purposes and as a means of recognition, while those of the fifth type are perhaps used mostly as a means of defense. Of the scent-producing organs used only for recognition, that of the honey-bee is probably the most highly organized.

ORTHOPTERA

In the ear-wig, *Forficula auricularis*, the scent-producing organ consists of two pairs of lateral, saclike invaginations located in the third and fourth abdominal terga. The walls of these sacs, the reservoirs, are composed of unicellular glands.

In both sexes of the roach *Corydia* two pairs of caruncles or evaginated saclike appendages serve as the scent-producing organ. These appendages are located on the pleura of the first and second abdominal segments. Unicellular glands lie in their walls. In the roach *Pteriplaneta* there appear to be at least three scent-producing organs. The males have anal glands and probably the females (the writers did not determine the sex) have a pair of lateral pouches in the articular membrane between the fifth and sixth abdominal

terga. These pouches are lined with hollow hairs into which the secretion from the unicellular glands empties. The same individuals also have a pair of tubular glands lying near the pouches. The same species has a fourth glandular structure lying in the sixth abdominal segment and opening between the sixth and seventh sterna. In the male roach *Phyllodromia germanica* the scent-producing organ consists of two double pouches, one of which lies in the articular membrane between the fifth and sixth, and the other between the sixth and seventh abdominal terga. The unicellular glands lie beneath the chitinous lining of these pouches.

In both sexes of the walking-sticks the secretion from the scent-producing organs is discharged through a pair of pores on the prothorax. The glands are paired, are ribbonlike blind sacs with stout walls, and lie in the mesothorax and prothorax. The gland cells certainly lie in the walls of these sacs, although information in regard to this point is wanting.

In two genera, *Eugaster* and *Ephippiger*, belonging to the Locustidæ, reflex bleeding occurs. The liquid issues from a pair of vesicles on the thorax near the bases of the front pair of wings. More information concerning the source of this liquid is lacking.

In the male cricket *Hadenæus subterraneus* the scent-producing organ is a pair of appendages protruded from slits between the ninth and tenth abdominal terga.

HEMIPTERA

Scale insects emit an odor, but the anatomy of the scent-producing organs has never been studied and the external openings of the glands have never been located.

In the adult heteropterous Hemiptera, the scent-producing organ is a pair of tubular glands located in the posterior part of the metathorax or in the anterior part of the abdomen. The secretion from the glands is emitted through a pair of pores between the bases of the second and third pairs of legs. In *Pyrhocoris apterus* a quite complicated organ is found; here there is a saclike cavity in the metathoracic sternum. A reservoir connects with the sac and a dichotomously branched, collecting tube runs from the kidney-shaped mass of unicellular glands to the reservoir.

TRICHOPTERA

The scent-producing organs of the male caddice fly, *Sericostoma personatum*, are the wide maxillary palpi. These appendages give off an odor, but the anatomy of them has not been studied.

COLEOPTERA

The simplest type of a scent-producing organ in beetles is composed of unicellular glands distributed over the entire body surface. In some beetles these unicellular glands are grouped and thus form glands varying considerably in complexity. In *Malachius* two pairs of caruncles serve as the scent-producing organs; unicellular glands lie in the walls of these structures. In *Dytiscus*, *Gyrinus*, and *Acilius* two different kinds of liquids issue from unicellular glands located in the articular membranes between the thoracic segments. The liquid emitted at the femoro-tibial articulation during the reflex bleeding of certain beetles seems to be secreted by two types of unicellular glands at this location.

The highest type of a scent-producing organ in all insects is the anal glands of beetles. These glands have been found in the following families and subfamilies: *Cicindelidæ*, *Carabina*, *Harpalina*, *Feroniina*, *Brachinina*, *Dytiscidæ*, *Gyrinidæ*, *Staphylinidæ*, *Silphidæ*, and *Paussidæ*. They are usually paired, vary considerably in complexity and are probably present in both sexes. The most complex form consists of an efferent canal, a spherical capsule, a reservoir, collecting tubes and unicellular glands, each of which contains a radial vesicle from which runs a secreting tubule to the collecting tube.

LEPIDOPTERA

Butterflies.—The scent scales on the wings constitute the almost universal type of scent-producing organs in male butterflies. A unicellular gland lies at the base of each scent scale. A pair of invaginated sacs located at the ventro-posterior end of the abdomen, has been found, however, in the males of *Danais septentrionales* and *Euplœa asela*. These sacs are partially lined with scent hairs and at the base of each hair lies a unicellular gland. In the female of *Euplœa asela*, the same organ is present, but in addition there is a circle of scalelike, scent hairs around the anus. In the female of *Gonopteryx rhamni*, the scent-producing organ is a single invaginated sac similarly located. In the females of the maracujá butterflies, a pair of styled knobs located at the posterior end of the abdomen serves as a scent-producing organ.

Moths.—The most common type of scent-producing organ in male moths is a tuft of scent hairs on the tibiæ of the third pair of legs. Occasionally, however, tufts of hairs are found on the tibiæ of the first and second pairs of legs. A unicellular gland lies at the base of

each scent hair. Another quite common type in male moths is composed of a pair of scalelike, scent hairs located at the base of the abdomen. Each tuft lies in a groove on either side of the body in the pleura belonging to the first and second abdominal segments. A large unicellular gland lies at the base of each scent hair. In the males of *Leucarctia* and *Pyrrharctia*, a pair of invaginated sacs located at the ventro-posterior end of the abdomen serves as a scent-producing organ; these sacs are lined with hairs.

In the female moths *Taumatopaa* and *Stilpnotia* the scent-producing organ consists of a paired tuft of scent hairs near the anus. This organ in the female of *Orgyia* is a scent groove in the articular membrane between the eighth and ninth segments just above the anus. Unicellular glands lie just beneath this thin membrane. The scent-producing organ in the female of *Bombyx mori* is the most highly developed of any found in the female Lepidoptera. This organ is a pair of invaginated and greatly folded sacs located at the posterior end of the abdomen; beneath the chitinous lining of these sacs lie the unicellular glands.

HYMENOPTERA

Ants emit characteristic odors, but as yet little is known about their scent-producing organs, nevertheless, a well-developed organ has been found in the petiole, besides unicellular glands beneath the articular membrane between the ninth and tenth abdominal terga, and also some around the femoro-tibial and tibio-tarsal articulations. A quite complicated, paired anal gland has been found in a few species belonging to one subfamily of ants. Many wild bees and wasps emit strong odors, but their scent-producing organs seemingly have never been described. This organ in the honey-bee consists of a pouch which is formed by the articular membrane between the fifth and sixth abdominal terga. Unicellular glands lying just beneath the membrane secrete a volatile substance which admirably serves as a source for odors.

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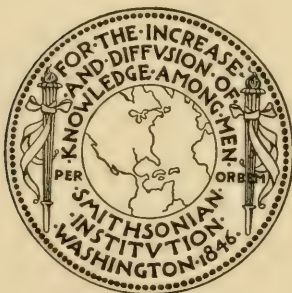
EFFECT OF SHORT PERIOD VARIATIONS OF SOLAR RADIATION ON THE EARTH'S ATMOSPHERE

(WITH EIGHT CHARTS)

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EFFECT OF SHORT PERIOD VARIATIONS OF SOLAR RADIATION ON THE EARTH'S ATMOSPHERE.¹

By H. HELM CLAYTON

WITH 8 CHARTS

INTRODUCTION

Several years ago the Director of the Astrophysical Observatory of the Smithsonian Institution announced the discovery of variations in the intensity of solar radiation with intervals of only a few days between the maxima and the minima of intensity.

It is a matter of interest and importance to determine whether these variations are coincident with atmospheric changes on the earth. Recently there was received from Dr. Abbot a pamphlet "On the Distribution of Radiation over the Sun's Disk and New Evidences of the Solar Variability" by C. G. Abbot, F. E. Fowle, and L. B. Aldrich (Smithsonian Misc. Coll., Vol. 66, No. 5). This pamphlet contained measurements made with the bolometer at Mt. Wilson, California, during the years 1913 and 1914 for the purpose of measuring the variability of the solar radiation. The results were determined in calories of heat per minute corrected to represent values outside the atmosphere.

In making a comparison between solar and atmospheric changes it was decided to use the method of correlation as worked out by Karl Pearson (see "Theory of Statistics" G. Undy Yule, London, 1912).

This method is the one used by the most modern investigators for comparing variables with each other, and is free from the error of personal bias which may enter when the investigator confines himself to curves and arithmetical averages.

The great varieties of local climate in the world caused by the distribution of land and water, mountain and valley, pole and equator, make it evident that any solar change may have very different effects in different parts of the world, and, hence, it seemed desirable for a first trial to select, out of the multitude of meteorological stations,

¹ Published simultaneously in English and Spanish with the consent of the Director of the Oficina Meteorologica Argentina.

one which in the light of our present knowledge might be expected to respond most readily to solar changes. A station situated in the center of a great continent, and in a tropical or subtropical region seemed, for this reason, the most favorable.

CORRELATION OF SOLAR RADIATION WITH TEMPERATURE AT PILAR

Pilar is a station in Central Argentina, lat. $31^{\circ} 39' S.$, long. $63^{\circ} 51' W.$, from which there were fairly complete and accurate observations at hand and appeared to meet these requirements.

The part of the day when the temperature appeared most likely to respond to solar changes was the afternoon; accordingly the afternoon maximum for each day was selected for the first trial.

The method usually employed in determining the correlation factor for two variables is, first to obtain the average value of each variable separately, and subtracting this from the individual observations, to obtain a set of residuals from which the correlation factor may be computed by the formula:

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \cdot \sum y^2}} \quad (1)$$

In the present case, the successive values of x are the departures of the individual observations from the average value of solar radiation during the period under consideration, and the successive values of y are the deviations of the temperature on each day from the mean of 30 days. In the observation of solar radiation of Mt. Wilson in 1913 there was a change in the mean value during the latter part of September, and, as this change corresponded closely with a change of instrument, it seemed best to divide the observations into two parts, one preceding September 23, and the other following that date. Dr. Abbot believes that a real change occurred in the mean solar values at that time; but as my object was to study the correlation of the short period solar changes with terrestrial meteorological changes of short period, it was desirable to eliminate any change in the mean value, by dividing the period into two. In 1914 there was no indication of an abrupt change in the mean values of solar radiation during the season, so that the deviations were taken from the mean of the whole season. The results are given in table 1 under the heading x . These values of x added to the mean value at the top of the column give the observed values at Mt. Wilson on the dates given in column 1.

In the case of the temperatures, it is also necessary to eliminate

the annual period, because changes due to the north and south movement of the sun are different from changes which may arise from the variability of the sun's heat. In order to eliminate the annual change of temperature and other changes of long period, monthly means were obtained, and from these means daily values were obtained by interpolation made arithmetically or by curves drawn through these values. If the mean of the daily maxima of temperature in September is 28.1° C. and that of October is 19.1° C. the mean daily change for the seasonal effect is 0.3° C., and successive daily values were obtained by subtracting 0.3° C. each day. Thus 28.1° would be the value for September 15; 27.8° for September 16; 27.5° for September 17; etc. Subtracting these values from the observed values a series of plus and minus values were obtained showing the short period oscillations of temperature. These deviations from the mean were arranged in tables in the following manner:

TABLE I

Solar radiation values		Temperature departures at Pilar. Maximum of each day. Degrees C.																	
Date	Deviations 1.929+		Days following the dates in column one																
	x	x^2	y					y^2					xy						
			0	1	2	3	4	0	1	2	3	4	0	1	2	3	4		
Aug. 3..	-1	1	0	3	4	-8	-8	0	9	16	64	64	0	-3	-4	8	8		
4..	-13	169	3	4	-8	-8	-5	9	16	64	64	25	-39	-52	104	104	65		
5..	29	841	4	-8	-8	-5	-3	16	64	64	25	9	116	-232	-232	-145	-87		
6..	-16	256	-8	-8	-4	-3	4	64	64	16	9	16	128	128	64	48	-64		
9..	28	784	-3	4	6	6	9	9	16	36	36	81	-84	112	168	168	252		
10..	25	625	4	6	6	9	12	16	36	36	81	144	100	150	150	225	300		
Etc.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sums....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

In this table the values under y in column (0) show the departures of the temperatures at Pilar on the same date as the solar measurements. Those in column (1) departures on the day following the solar measurements, etc., up to four days after the solar measurements. The values under y^2 show the values of y squared (yy), and the values under xy show the product of the radiation deviations x and the temperature deviations y . From a table like table I the data were obtained for use in formula 1.

The values of the correlation coefficient for Pilar obtained in this way for 1913 and 1914 were as follows:

TABLE 2.—*Correlation Factors Computed from Observed Values*

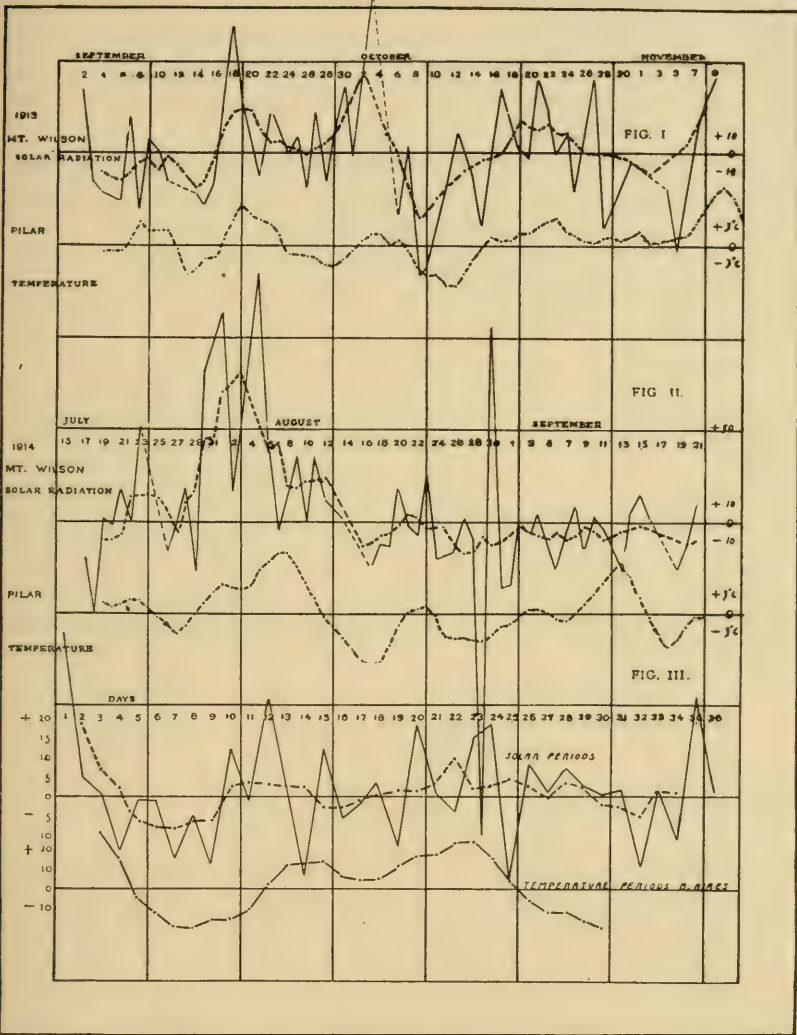
Days following solar observations	0	1	2	3	4	5	Prob. error of max.
(1) July 16 to Aug. 24, 1913.....	.14	.26	.23	.22	-.06		±.09
(2) Sept. 25 to Nov. 9, 1913.....	.31	.44	.38	.31	.20	.00	±.09
(3) June 12 to Aug. 28, 1914.....	.19	.26	.10	-.10	-.35		±.09
(4) July 30-Aug. 5 and Aug. 29-31, 1914.	.38	.45	.78	.73	.47	.45	±.12
(5) Sept. 1 to Oct. 20, 1914.....	-.04	-.34	-.26	-.12	-.07		±.10
(6) All observations, 1913.....	.20	.32	.29	.27	.07		±.07
(7) All observations, 1914.....	.13	.14	.21	.18	.02		±.07
(8) Mean of 1913 and 1914.....	.16	.23	.25	.23	.04		±.05

In computing the values under (3), certain large values which were considered doubtful by Dr. Abbot and his associates were omitted. The correlation factor was computed separately for these large deviations, and found to be very high as seen by the results under (4) where the maximum correlation is nearly seven times as great as the probable error. In every case excepting the interval September to October, 1914, a positive correlation was found with the maximum three to five times as great as the probable error. The maximum coefficient for all the observations 1913 to 1914 in (8) although not large, proves to be five times the probable error, so that, according to accepted standards, there is proved to have been a positive correlation during these years between variations in solar radiation as measured at Mount Wilson, in the United States, and variations in daily maxima of temperature at Pilar, in Argentina. The maximum correlation follows one to two days after the corresponding solar values. In this respect the retardation is analogous to other solar effects.

The maximum temperature of the day lags two to three hours behind the meridian passage of the sun, and the maximum temperature of the year lags about a month behind the time of greatest altitude of the sun. In each case the lag is one-tenth to one-twelfth of the length of the period and by analogy irregular fluctuations of 5 to 15 days between maxima would show a lag of one to two days. It is also worthy of note that the largest variations (4, table 2) not only showed the maximum correlation, but also the greatest lag. Even up to the fifth day the correlation was positive and nearly three times the probable error. The probable error was determined by the formula:

$$P. E. = \frac{(1-r^2)}{\sqrt{n}} \quad (2)$$

The next step was to plot the observations of solar radiation and temperature. From this plot, it became evident that the minor fluctuation of solar radiation of two to five days between the maxima were reflected in the temperature to a much less extent than were the longer



FIGS. I, 2, 3

oscillations. For this reason, an attempt was made to smooth out the small irregularities by taking the mean of all the observations of solar radiation during each successive interval of five days. In one or two cases where there were only two observations within the five

days this interval was extended to six days. The observed departures and the smoothed means are given in table 4.¹ The results are plotted in figures 1 and 2 in which the observed departures for 1913 and 1914 are connected by continuous lines and the means for each successive five days are joined by broken lines. Under these in each case are plotted the successive five-day means of temperature at Pilar for the same intervals. It is evident to the eye that these temperature changes followed the same general course as the changes in solar radiation shown by the five-day means.

Calculations were now made to determine the correlation values for the five-day means of solar radiation observations and the five-day means of the daily maxima of temperature observed at Pilar. In these calculations account was taken of the tenths of degrees instead of using departures to whole degrees as in the first computation. (See table 1.)

The results obtained from this computation were as follows:

TABLE 3.—*Correlation of Solar Radiation and Temperature at Pilar from 5-Day Means*

Days following solar observations	0	1	2	3	4	5	Prob. error of max.
<i>Correlation using maximum temperature of day</i>							
1913, Aug. 5 to Nov. 8.....	.32	.51	.54	.48	.33	.13	± .060
1914, July 19 to Sept. 20.....	.51	.53	.52	.48	.43	.38	± .068
Mean.....	.41	.52	.53	.48	.38	.25	± .048
<i>Correlation using mean temperature of the day</i>							
1913, Aug. 5 to Nov. 8.....	.07	.27	.35	.35	.28	.14	± .075

By comparing tables 2 and 3 it is seen that the correlation factor is much higher for the mean of five days than for the individual observations being nine times the probable error in 1913, and nearly eight times in 1914. This increased agreement may be due to the fact that the individual solar measurements are approximate, varying on each side of the true result, or, else, that the changes of short period are too rapid to produce any appreciable change on the earth.

To determine whether a better result would be obtained by using the mean temperature of each day instead of the maximum, the correla-

¹ Note. Table 4 is omitted in the English text.

tion coefficient for the mean of five days was computed in the same way as for the preceding results, and the correlation factors are given in the last line of table 3.

The maximum correlation factor is nearly five times larger than the probable error, but is smaller than the correlation factor in the case where maximum temperatures alone were used.

CORRELATION OF SOLAR RADIATION WITH TEMPERATURE IN VARIOUS PARTS OF THE WORLD

The results obtained from Pilar were so favorable that it was decided to extend the computation to observations made in other parts of the world using the departures of the daily maxima of temperature as explained in the case of Pilar. See chart 8.

For this purpose data were obtained from the following publications:

Anuario Meteorológico, Chile, 1913.

Monthly Weather Review, United States, Vols. 1 to 13, 1913.

Observations from British Colonies, 1913, reprinted from Colonial "Blue Books"—Nigeria, Uganda, Nyasaland, Seychelles, Bermuda, Jamaica, Georgetown, Mauritius, Fiji, Hong-Kong, Gambia.

Report of the Meteorological Service of Canada, 1913.

Osservazioni Meteorologiche y Geofisiche fatte nel R. Osservatorio Astronomico di Brera in Milano, 1913.

Meteorologische Beobachtungen Angestellt in Jurjew (Russia), 1913.

Meteorologiske Iktagelser i Sverige, 1913.

Danske Meteorologiske Aarbog 2 den Del Ferøerne, Island, Grønland og Vestindien, 1913.

Boletín Mensual de la Sección Meteorológica del Estado de Yucatan (Mexico), 1913.

Boletín Mensual del Observatorio del Ebro, 1913.

Bulletin of the Philippine Weather Bureau, 1913.

The means of each successive five days were obtained for each set of observations, and the correlation factors calculated by comparison with the mean values of solar radiation as given in part 2 of table 4.¹

Calculating first the factor for Arica, Peru, similar results to those of Pilar were found. Then computing the results for Kingston, Jamaica, a station somewhat north of the equator, a positive correlation resulted as was the case also for Roswell, N. M., a continental station in the southern United States, about the same latitude north as Pilar is south of the equator.

The computations were next made for San Francisco and San Diego, California, and showed a marked negative correlation. The

¹ Note. Table 4 is omitted in the English text.

results for Denver and Chicago also showed a negative correlation, but going northeastward to St. Johns, Canada, and to Jacobshavn on the west coast of Greenland, and northwestward to Dawson, Yukon territory, a second band of positive correlation is found. Next going southwards from Pilar, negative correlations are found at Valdivia, and Punta Arenas, Chile, and a positive correlation at the South Orkneys near the Antarctic circle indicating very clearly that the tropical and subtropical land stations in the western hemisphere are subject to temperature changes similar to the changes of solar radiation, while the changes in the temperate regions are in the reverse direction and those near the Arctic circle are again similar to the solar changes. This arrangement corresponds closely with the arrangement of the high and low pressure belts of the world. Computations were next made for land stations in tropical Africa, for Mauritius, for Manila, and for a station in the Fiji Islands. The results are given in table 5 arranged according to different zones shown in the table.

The means of these results indicate a maximum positive correlation in the tropics on the second day following the solar observations, a maximum negative correlation in the temperate zone and subtropical oceans on the third to fourth day following the solar observations and a maximum positive correlation on the second day in the Arctic Zone.

The later occurrence of the negative correlation indicates that it is a secondary result of the solar action in other parts of the world.

The most probable explanation is that tropical areas, and especially the tropical land areas, are the parts most heated by the increase of solar radiation.

This heating causes an expansion of the air over the tropics and an overflow toward the temperate zones, particularly towards the cooler ocean areas in this zone. The final result would be a fall of pressure in the tropics and a rise in the temperate regions causing an intensification of the normal pressure belts of the earth.

That this is a process which actually takes place seems borne out by the fact that the negative correlation factors are largest on the west coasts of continental land masses near the 35th latitude as at San Francisco and San Diego in the north and at Valdivia in the south, where an increase of intensity in the oceanic centers of high pressure would cause an increase of polar winds; while on the east coast of the land masses as at St. Johns, New Brunswick, the positive

TABLE 5.—*Correlation of Solar Radiation with Temperature in Various Zones of the Earth from 5-Day Means, 1913*

Tropical Stations and Subtropical Land Stations

Days following solar observations			0	1	2	3	4	5
Station	Latitude	Longitude						
Pilar.....	31° 39' S	63° 5' W	.32	.51	.54	.48	.33	.13
Arica.....	18° 29' S	70° 20' W	.30	.34	.36	.36	.36	.36
Kingston.....	17° 58' N	76° 41' W	.20	.22	.20	.07	.02	.15
Roswell.....	33° 24' N	104° 27' W	.18	.15	.07	.01	.00	.04
Zungeru.....	9° 49' N	6° 10' E	.28	.43	.47	.35	.20	.02
Entebbe.....	0° 5' N	32° 28' E	.23	.17	.13	.02	.03	.08
Zomba.....	15° 23' S	35° 18' E	.11	.20	.30	.40	.44	.37
San Isidro.....	15° 22' N	120° 53' E	.44	.49	.50	.48	.44	.35
Mean.....			.26	.31	.32	.27	.22	.11

Stations in Temperate Zone and in Semi-Tropical Oceanic Areas

Sacramento.....	38° 35' N	121° 31' W	.27	.04	-.21	-.35	-.46	-.41
San Diego.....	32° 43' N	117° 10' W	.18	-.10	-.29	-.50	-.52	-.44
Denver.....	39° 45' N	105° 0' W	-.05	-.03	-.02	-.09	-.20	-.33
Chicago.....	41° 33' N	87° 37' W	-.42	-.38	-.31	-.18	-.03	-.12
Winnipeg.....	49° 53' N	97° 7' W	-.13	-.24	-.26	-.24	-.17	-.08
Jurjew.....	58° 22' N	26° 43' E	.17	.07	-.05	-.13	-.23	-.26
Milan.....	45° 25' N	9° 10' E	-.40	-.41	-.27	-.12	.03	.09
Valdivia.....	39° 48' S	73° 15' W	.08	-.02	.10	-.15	-.17	-.15
Punta Arenas.....	53° 10' S	70° 54' W	.19	-.01	-.04	-.19	-.18	-.17
Mauritius.....	20° 6' S	58° 33' E	-.37	-.47	-.44	-.31	-.22	-.18
Suva, Fiji.....	18° 8' S	178° 26' E	-.19	-.18	-.11	-.10	-.11	-.08
Mérida.....	20° 50' N	89° 40' W	-.03	-.10	-.15	-.21	-.19	-.16
Mean.....			-.04	-.16	-.19	-.21	-.20	-.17

Stations near Arctic Circle

Dawson.....	64° 4' N	130° 20' W	.26	.25	.23	.24	.26	.23
Jacobshavn.....	69° 13' N	51° 2' W	.33	.26	.27	.18	.07	-.07
Stykkisholm.....	65° 5' N	22° 46' W	-.10	-.09	-.04	.01	.09	.15
Haparanda.....	65° 50' N	24° 9' E	.16	.10	.02	.04	-.08	-.08
St. Johns, N. B.....	45° 17' N	66° 4' W	.41	.45	.46	.42	.40	.29
Laurie Island.....	60° 44' S	44° 39' W	.18	.21	.14	.09	.04	.03
Mean.....			.20	.20	.21	.16	.13	.09

Intermediate Stations

South Georgia.....	54° 14' S	36° 33' W	.08	.13	.08	.00	-.05	-.04
Ebro, Spain.....	40° 49' N	0° 30' E	-.14	-.05	.07	.15	.16	.15
Bathurst, Gambia..	13° 24' N	16° 36' W	-.35	-.39	-.24	-.13	-.06	-.10
Hong-Kong.....	22° 18' N	114° 10' E	-.22	-.25	-.37	-.40	-.36	-.24

correlation belt of the north extends far to the south, owing to the increase of winds from the direction of the equator arising from the increase of pressure over the Atlantic near the 35th parallel.

CORRELATION OF SOLAR RADIATION WITH ATMOSPHERIC PRESSURE

To ascertain to what extent the pressure responded to temperature changes the next step was to determine the correlation of the solar radiation with changes in atmospheric pressure. The observations of pressure made nearest 2 p. m. of each day at a few selected stations were treated in the same manner as in the case of the temperature. Mean values were obtained for each day by interpolation between monthly means, and these means were subtracted from the observed values to obtain the plus and minus departure showing the short period changes in pressure. These departures were then correlated with the short period changes of solar radiation and the results are given in table 6.

TABLE 6.—*Correlation of Solar Radiation with Pressure in Various Zones of the Earth from 5-Day Means*

Days following solar observations			0	1	2	3	4	5
<i>Tropical stations</i>	<i>Latitude</i>	<i>Longitude</i>						
Kingston, Jamaica..	17° 58' N	76° 41' W	.15	.12	.08	-.02	-.09	-.17
Zungeru, Africa....	9° 49' N	6° 10' E	.01	.07	.04	-.03	.00	.06
Entebbe, Africa....	0° 5' N	32° 28' E	-.32	-.27	-.23	-.08	.05	.06
Mean.....			-.05	-.03	-.04	-.04	-.01	-.02
<i>Temperate regions</i>								
Valdivia, Chile.....	39° 48' S	73° 15' W	.09	.08	.10	.09	.04	-.01
Jurjew, Russia.....	58° 22' N	26° 43' E	.09	.12	.15	.17	.22	.17
Mean.....			.09	.10	.12	.13	.13	.08
<i>Arctic Circle</i>								
Stykkisholm.....	65° 3' N	22° 46' W	.05	-.01	-.06	-.08	-.12	-.15
Laurie Island.....	60° 44' S	44° 39' W	.19	.08	.05	.03	-.01	.02
Mean.....			.12	.04	.00	-.03	-.07	-.07

These various values of the correlation factor are plotted in figure 4.

In this figure, *A* shows the mean of the correlations of temperature for the tropical stations and subtropical land stations, *B* the mean of the correlations of pressure for the tropical zone (inverted), *C* the mean of the correlations of pressure for the temperate zone, *D* the mean correlations of temperature for the temperate zone (inverted), *E* the mean of the correlations of pressure for the Arctic circle (inverted), and *F* the correlation of the temperature for Iceland.

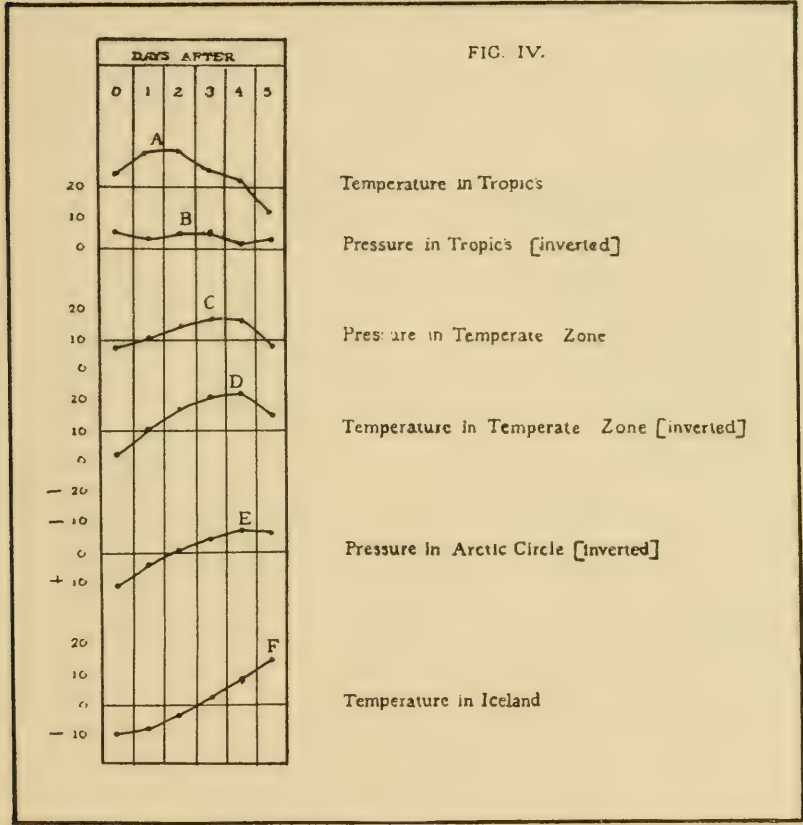


FIG. 4

In each zone the pressure correlation was the reverse of that of the temperature, when one was positive the other was negative. In the plot the negative correlations were inverted or treated as positive in order to show the progressive series of events from *A* to *F*.

This plot indicates very clearly that in the tropical regions the temperature rises and falls in unison with changes of solar radiation, but follows the solar changes about two days. Following this

rise of temperature the pressure falls in the tropics attaining a minimum between the second and third day after the solar change. On the succeeding day the pressure attains a maximum in the temperate region and the temperature a minimum. Succeeding this maximum one day, that is, four to five days after the solar changes, is a minimum of pressure in the Arctic circle near the 60th degree of latitude in both hemispheres, and a maximum of temperature in the oceanic centers of low pressure like that near Iceland.

This succession of results suggests the flow of air from the tropics to the Arctic circle and brings to the attention of meteorologists a new kind of weather change not heretofore considered in daily forecasting.

This class of change is entirely different and distinct from the ordinary class of weather changes used in weather forecasting.

These latter changes usually move from west to east with an equatorial component of motion and are of a very complex nature analogous to a series of waves of different lengths moving with different velocities. (See U. S. Weather Review, Vol. 35, April, 1907; Quar. Journal Royal Meteorological Society, Vol. 41, pp. 201-207, July, 1915; Historia y Organización del Servicio Meteorológico Argentino, 1914.)

A plot of the correlation factors found for the different stations is made on a map of the world in chart 2. In this map the belts of high and low pressure of the earth are shown by colors, the white areas indicating areas of low pressure and the red tints, belts of high pressure. This tinted area is taken from the charts of Buchan for October (Climatological Atlas by Alexander Buchan, Report of the Scientific Results of the Voyage of H. M. S. Challenger) this month being near the middle of the period covered by the observations.

In making this map there was a choice of plotting the maximum positive or negative correlation at each station or else of plotting the correlation on a given day following the solar changes. Both methods were tried, and do not differ greatly as regards the distribution of the positive and negative values. In chart 1 the correlation values for temperature are given for the same day at all the stations, namely for the third day following the solar changes. This left the chart free from any personal bias in selection when there were nearly equal positive and negative values.

Lines were then drawn separating the positive and negative regions. No data were accessible from the central Atlantic Ocean or from central Asia and the lines in these regions are drawn to accord with results from similar regions.

The areas of positive correlation are colored red, and the negative white. These show very clearly the arrangement of the positive tropical belt widening over the land, and contracting over the ocean (possibly disappearing), and the belt of negative correlation in the temperate zone widening over the oceans and contracting over the land. Beyond this is a belt of positive correlation near the Arctic circle widening out near the east coast of the continent where the distribution of pressure over the oceans gives rise to winds with a component of motion from the equator.

Next the pressure correlations were plotted for the third day following the solar changes (see chart 2).

On this chart are plotted the belts of high and low pressure of the earth as shown on the charts of Buchan for October, this month being near the middle of the period covered by the observations. The region where the mean pressure is below 760 mm. is colored white, and that above is colored red. It is seen that in every case except one, the correlation is negative in the belts of low pressure of the world. In other words, the effect of an increase of solar radiation is to intensify these belts. It will be noted also how closely the belts of positive and negative temperature correlations correspond in a reverse sense to that of pressure, indicating that the pressure changes which have a smaller correlation factor are the result of the temperature changes induced in the air by variation of solar radiation. It is known that the pressure belts vary with the seasons, and it is probable that the effect of solar changes differs with the season in the various parts of the earth. For example, in the central United States the pressure is low in early summer with an excess of southerly winds, while in winter it is high with an excess of northerly winds in the same region. It is hence conceivable that the same change in solar radiation might have an opposite effect in the two seasons, showing a positive correlation in the one and a negative in the other.

COMPARISON OF INDIVIDUAL MAXIMA OF SOLAR RADIATION WITH TEMPERATURE IN VARIOUS PARTS OF THE WORLD

In studying the variations of temperature in detail as compared with the variations of solar radiation, it becomes very apparent that the effect of the solar change does vary from negative to positive at the same place, and while there may be a seasonal change there are also changes which cannot be explained in this way, and the reason for which remains yet to be found.

As examples of this there are plotted in figure 5, first the mean solar variations and below this curve the five-day means of temperature at San Isidro, Manila, Philippine Islands, at St. Johns, N. B., Canada, at Stykkisholm, Iceland, at Sacramento, Cal., United States, at Zungeru, Nigeria, Africa, at Pilar, Córdoba, Argentina, and at

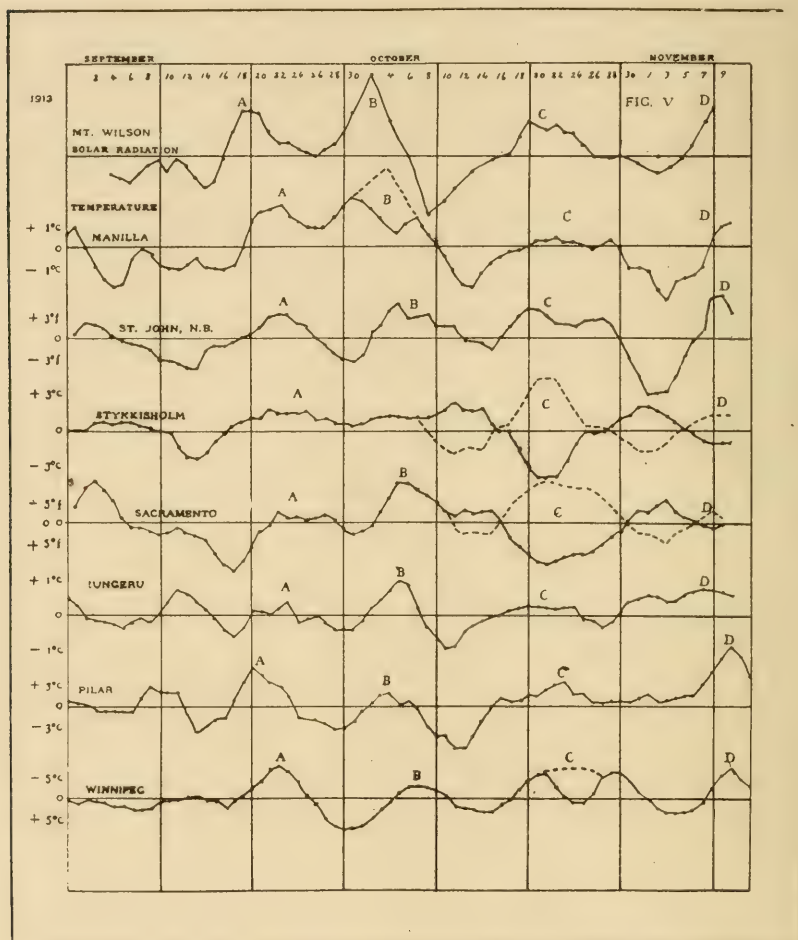


FIG. 5

Winnipeg, Man., Canada. The Sacramento and the Winnipeg curves are inverted, that is the minus quantities are plotted above the zero line and the plus below.

It will be noted that all the curves are more or less similar, but none follows exactly the solar variations. For example, the Manila

curve shows a slight minimum about October 5, not indicated by the solar curve. The St. John's curve, instead of showing the greatest minus variation about October 11, as indicated by the solar curve shows the greatest minus variation about November 3. The Stykkisholm curve follows the solar variation until about October 6, after which it becomes inverted as indicated by the light broken curve. The Sacramento curve follows the solar radiations in an inverse sense until October 10, after which it varies directly with the solar radiation as indicated by the light broken curve. The curve for Winnipeg is inverted throughout, but shows a tendency to a direct correlation about October 24.

These diverse effects appear to be associated in some way with shifts in the centers of action in the atmosphere, as for example, the shift of the anticyclonic center in the Atlantic and Pacific oceans, and that of the low pressure centers near Iceland and the Aleutian Islands.

In order to study the changes accompanying each individual maximum of solar radiation *A*, *B*, *C*, and *D*, figure 5, the deviations of temperature accompanying each solar maximum were plotted on charts. The dates of the solar maxima were taken as September 19, October 2, October 19 and November 8. Supposing that in the average for the whole world the greatest departures of temperatures would follow these solar maxima about three days the dates were taken as September 22, October 5, October 22 and November 11.

The deviation of the five-day means from monthly means on these dates for the various stages of the world were plotted on maps. The five-day means were for the day of observation and the two days following and the two days preceding the date. The monthly means were for the 15 days preceding and 15 days following the given dates.

In figure 5 the zero lines represent the 30-day mean and the plotted lines the deviations from this mean. It will be seen from this chart that on October 22, the departure at San Isidro, Manila, was $+0.5$, while at Stykkisholm it was -3.7 .

After plotting this data on maps, lines were drawn separating the plus from the minus areas and also lines were drawn around the stations showing maximum departures.

An inspection of the charts 3, 4, 5, and 6 reveals the fact that the centers of maximum departure are not fixed but show a tendency to shift from point to point on the earth's surface. On chart 7 the centers are plotted as well as could be done from the meager data at hand, and they indicate an oscillation of the maxima around the

centers of the continental and oceanic masses. There is one center oscillating around the center of South America, another around the center of North America, and another around the center of Africa.

The changes in the other centers are more difficult to determine, but there appears to have been a maximum which moved from southern Greenland up to Jacobshavn, and back again to St. Johns New Brunswick, a minimum which moved from Jurjew, Russia, to Stykkisholm, and back again to northern Europe, and a maximum in the South Atlantic which moved from South Georgia to Laurie Island. There were also indications of a minimum which moved from the Central Atlantic to the coast of Spain during October, and another which moved from the Central Pacific to the coast of Chile at the same time. There were no doubt other centers in Siberia, Australia, the Indian ocean, the South Atlantic and Pacific oceans. An extremely interesting point is that all those centers, whose motion could be approximately determined, oscillated in the anticlockwise manner in both hemispheres, reached their most northern point in October, and the most southerly in September and November with one or two exceptions.

This movement of centers of oscillation is very similar to a phenomenon of the same kind found some years ago in the United States when studying temperature oscillations of about two years' corresponding no doubt with oscillation in solar radiation of longer period. (American Meteorological Journal, Vol. 2, p. 126, Detroit, 1885.) I am led to infer that an oscillation in the areas of positive and negative departures is characteristic of all effects of solar changes on the earth's atmosphere and has been one of the reasons why the relation between atmospheric phenomena has been difficult to detect, and why periodic changes of all kinds have been masked.

PERIODIC CHANGES IN SOLAR RADIATION AND IN THE TEMPERATURE AT BUENOS AIRES

An interesting line of inquiry is in regard to whether any periodicity can be detected in the changes in solar radiation. Many years ago, Prof. Balfour Stewart used a method of seeking hidden periodicities by means of averages of periods of successively greater length. Prof. Arthur Schuster gave a greater refinement to this method by the use of harmonic analysis and the construction of a *periodogram*. This method assumes that there are fixed periods to be discovered, but there is a possibility of a kind of periodicity without a fixed epoch. For example the spots on the sun reappear near the same part of the

solar surface as seen from the earth at intervals of about 27 days, the length of a solar rotation.

This is a true solar period but would not be indicated by the method of averages used by Stewart and Schuster because spots are continually disappearing, and new spots appearing in other parts of the sun.

For periodicities of this class the method of correlation offers a method of research which I have tried successfully in studying meteorological periods. Even if a period reverses its phase from time to time this method would still bring out the period.

The method consists in obtaining the correlation factor for intervals of successively greater lengths. For example, all the solar radiation measurements so far as the observations permit are correlated with those made one day later, two days later, three days later, and so on to any successive maxima of correlation indicating periods of a length corresponding to the interval shown by the maxima.

The unsmoothed measurements of Abbot, Fowle, and Aldrich in 1913 were treated in this manner with the following results:

TABLE 7.—*Correlation Factors for Different Periods*

Length of period days.....	1	2	3	4	5	6	7	8	9	10	11	12
Correlation factor.....	.47	.05	.00	-.15	-.01	-.01	-.17	-.05	-.18	-.13	-.01	.27
Mean of five.....			.07	-.02	-.07	-.08	-.08	-.06	-.05	.03	.05	.04
Length of period days.....	13	14	15	16	17	18	19	20	21	22	23	24
Correlation factor.....	.02	-.22	.13	-.06	-.02	.04	-.13	.18	.01	-.04	.16	.20
Mean of five.....	.04	.03	-.03	-.03	-.01	.00	.02	.01	.03	.10	.02	.04
Length of period days.....	25	26	27	28	29	30	31	32	33	34	35	36
Correlation factor.....	-.22	.09	.02	.08	.03	.01	.02	-.18	.02	-.12	.28	.01
Mean of five.....	.05	.03	.00	.05	.03	-.01	-.02	-.05	.00	.00	.....	.....

These results are plotted in figure 3. They show chief maxima at 0, 12, 23 to 24, and 35 days indicating a period of about $11\frac{2}{3}$ days. There are secondary maxima at 5, 10, 15, 20 days indicating a less marked period of five days. The probable error of the maximum on the 12th day is $\pm .094$ or about $\frac{1}{3}$ of the computed correlation value.

The means of each consecutive five values of the correlations are shown by the broken curve. These show two maxima, a chief one at 22 days and a secondary maximum at 17 to 14 days.

Underneath this solar curve is plotted a curve of correlation factors computed from the 8 a. m. and 8 p. m. temperatures observed at

Buenos Aires during the summer of 1913. The departures of the temperature from the daily normals of 50 years for 184 observations in June, July and August (92 days) were correlated with the temperature departures occurring three days later, four days later, etc., up to 30 days later.

These computations were made nearly a year preceding the reception of the solar data.

The curve derived from the computed correlations is very regular and is very similar to the curve drawn from the mean of each consecutive five of the solar factors. In the temperature curve the chief maximum is on the 22d day of the period and has a value of .25 with a probable error of $\pm .047$. In this case the correlation factor, while not large, is more than five times the probable error. The data entering into this latter curve were computed earlier than those entering on the solar curve, and its close resemblance to the mean solar correlations, shown by the broken curve in figure 3 is another proof of the connection between solar changes in radiation and terrestrial meteorological changes, and is also a proof of the reality of a period of about 22 days.

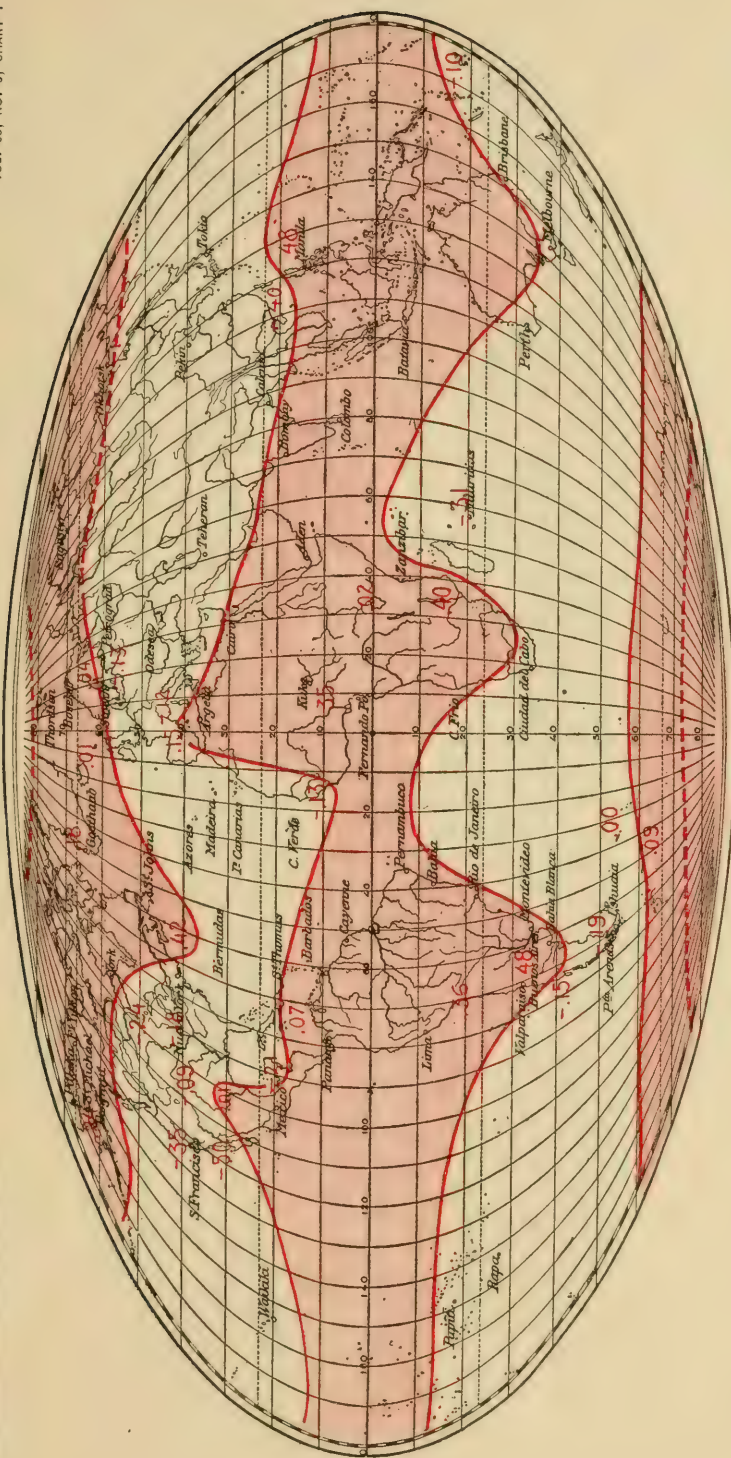
This period is shorter than the period ordinarily assumed for a solar rotation and leads one to suppose that it has some other origin.

SUMMARY

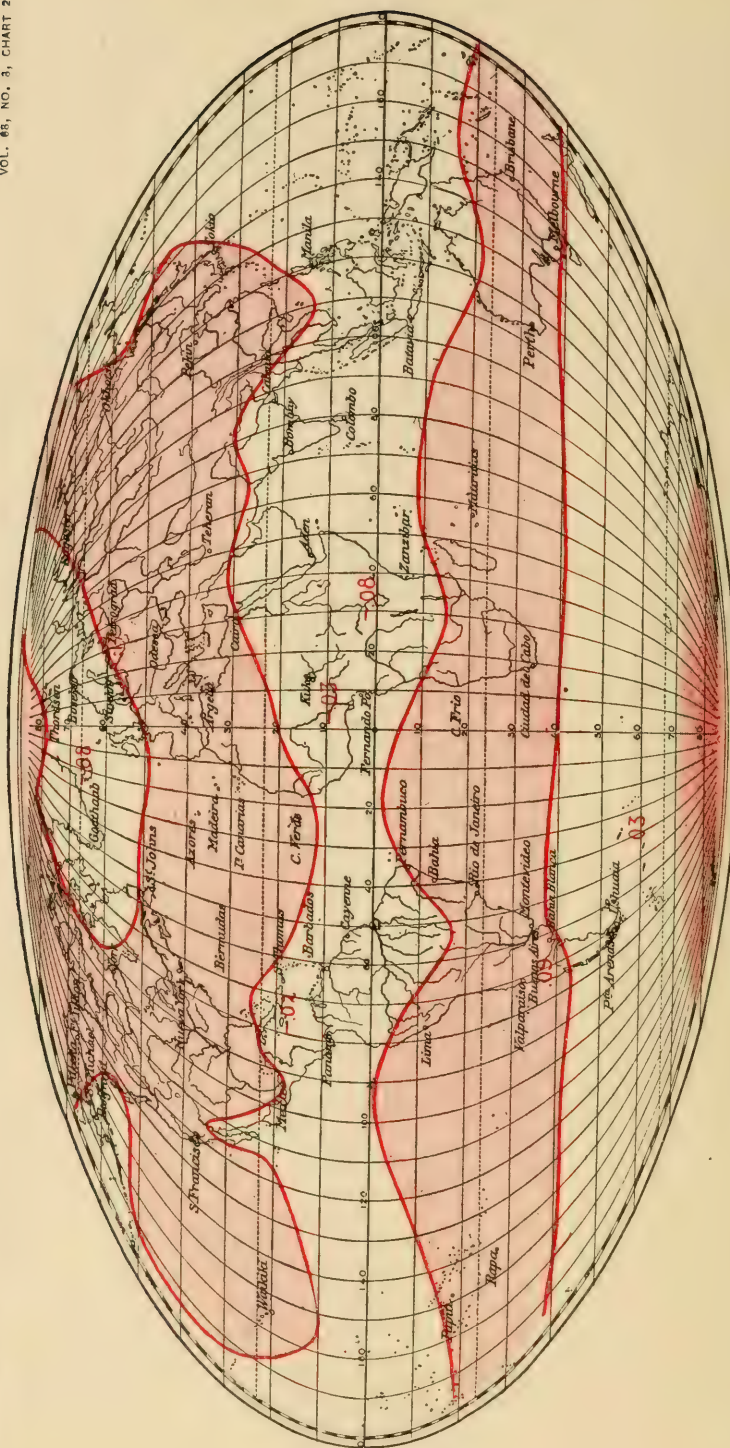
Two important conclusions are derived from this study:

(1) That there is an intimate relation between solar changes and meteorological changes of short period, and that measurements of solar radiation like those made by Dr. Abbot and his associates have the greatest importance for meteorology.

(2) That there is a class of meteorological changes which have their origin in equatorial regions and by a transference of air, probably in the upper layers, are felt within a few days in higher latitudes. These changes are the complement of the complex meteorological drift which goes from west to east in temperate latitudes with a component of motion from pole to equator in both hemispheres.

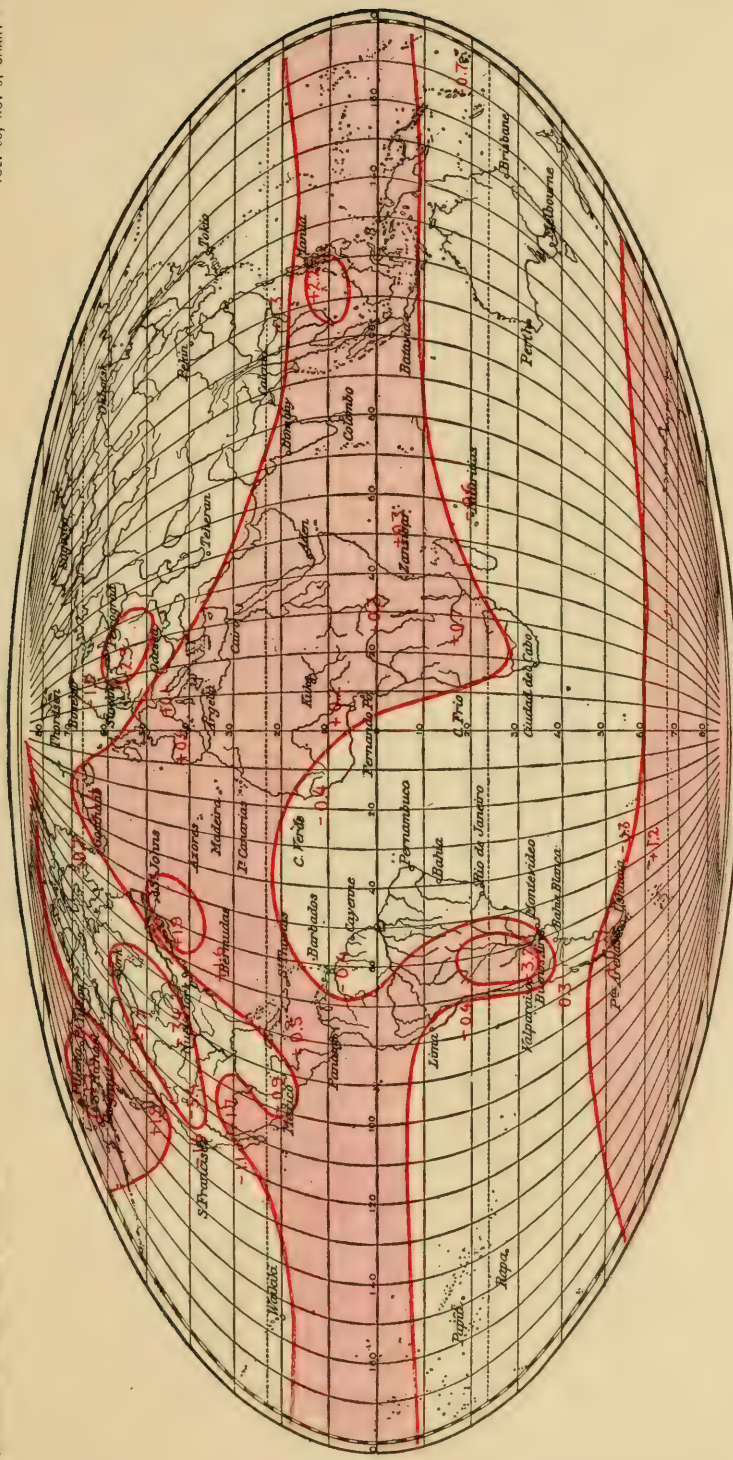


CORRELATION SOLAR RADIATION AND TERRESTRIAL TEMPERATURE--RED NUMERALS.
Red areas, belts of positive correlation.
White areas, belts of negative correlation.

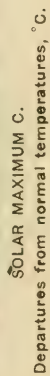


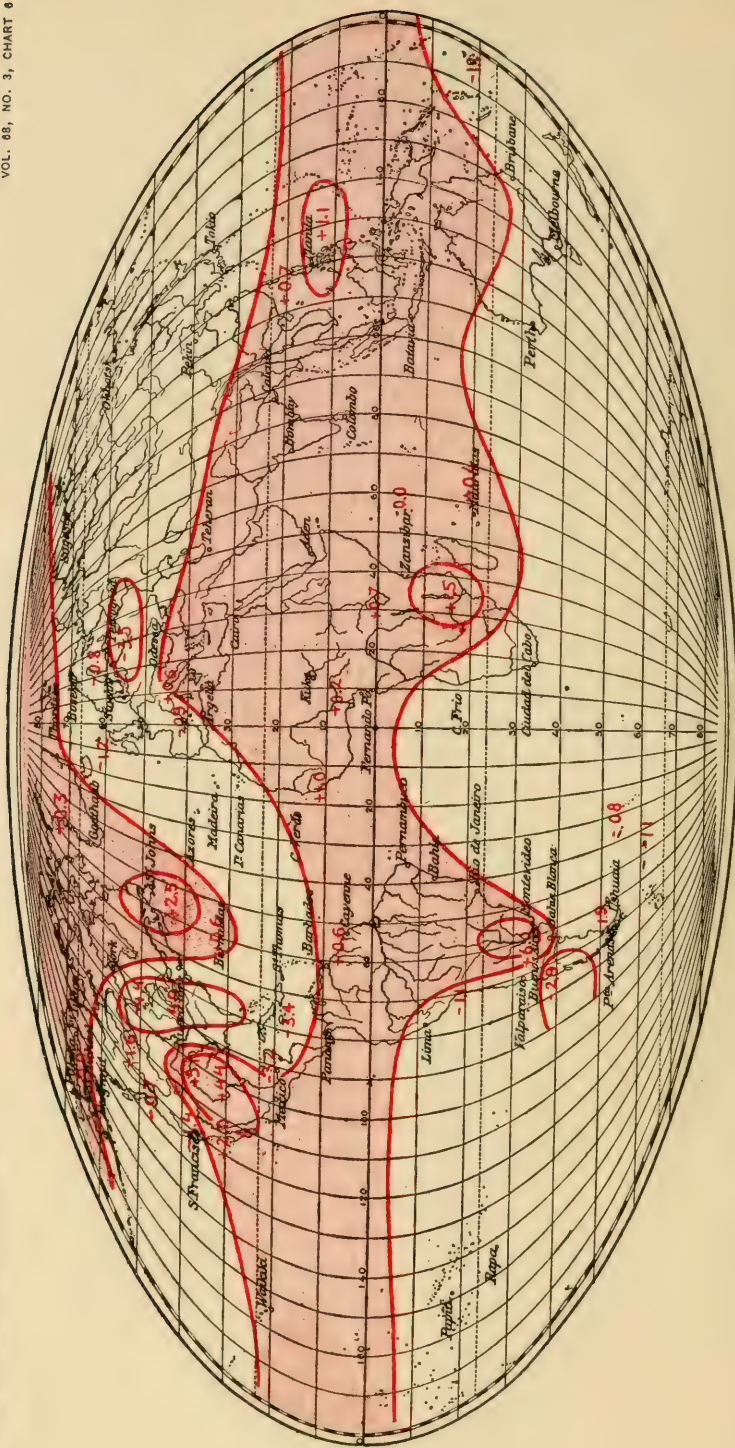
CORRELATION SOLAR RADIATION AND ATMOSPHERIC PRESSURE—RED NUMERALS.

Red areas, normal belts of high pressure—Büchan.
 White areas, normal belts of low pressure—Büchan.

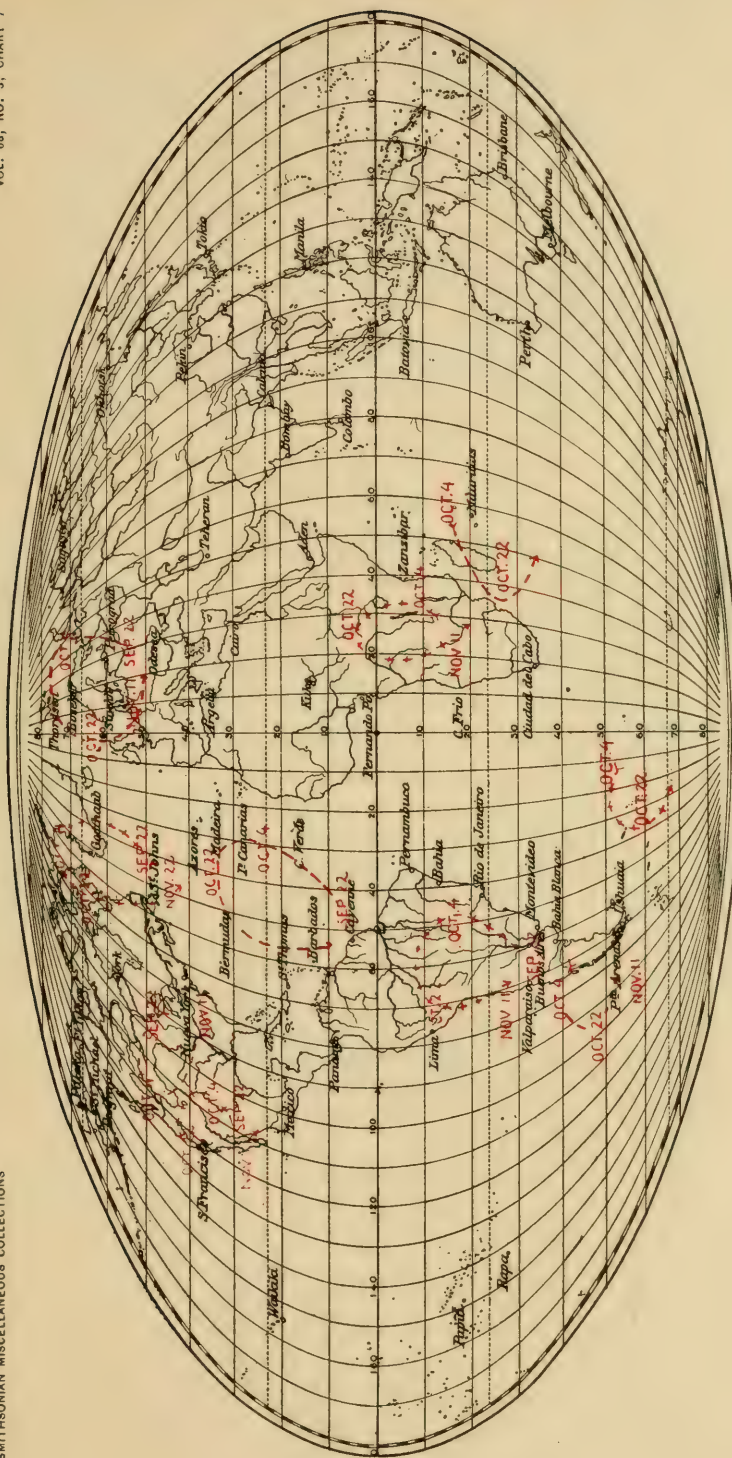


SOLAR MAXIMUM A.
Departures from normal temperatures, ° C.



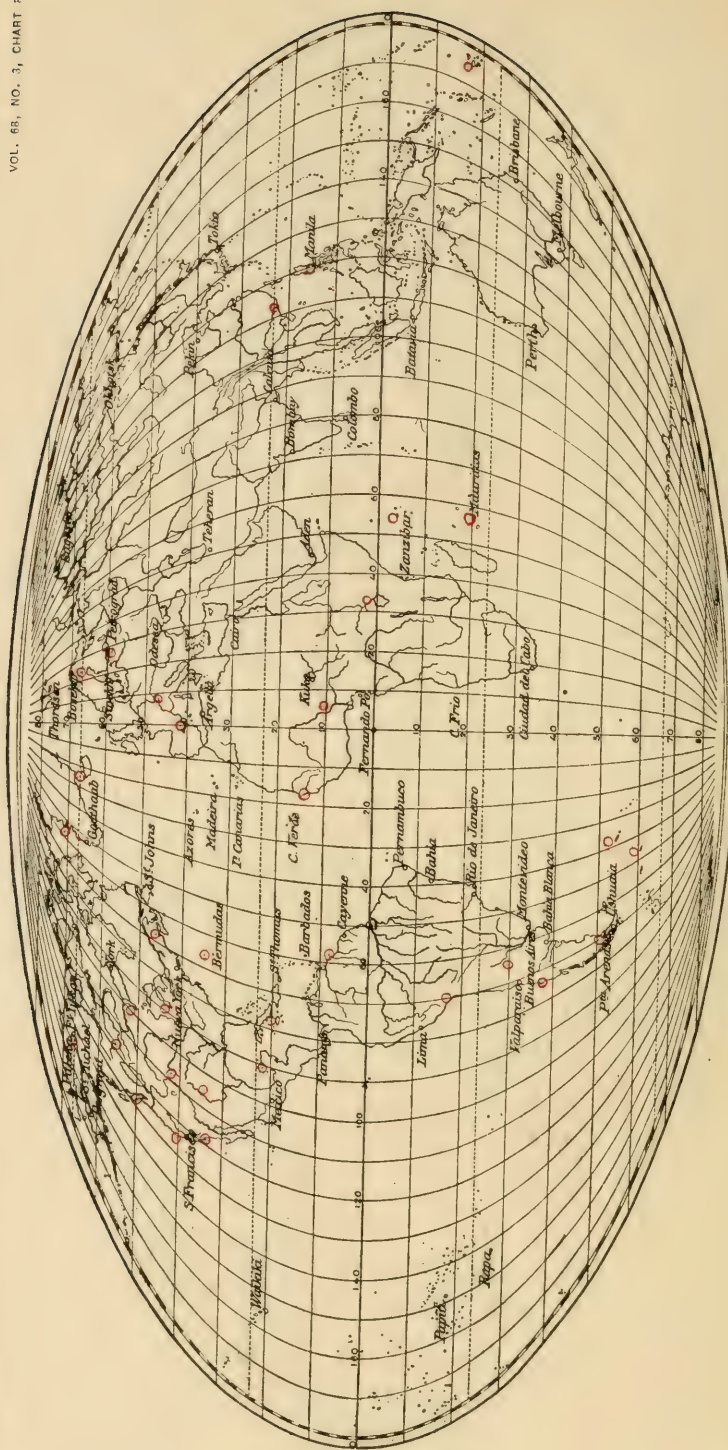


SOLAR MAXIMUM D.
Departures from normal temperatures, °C.



MOVEMENT OF CENTERS OF GREATEST DEPARTURE.

Positive + + + + +
Negative - - - - -



POSITIONS OF STATIONS USED.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

VOLUME 68, NUMBER 4

PRELIMINARY DIAGNOSES OF NEW MAMMALS OBTAINED
BY THE YALE-NATIONAL GEOGRAPHIC SOCIETY
PERUVIAN EXPEDITION

BY
OLDFIELD THOMAS
British Museum



(PUBLICATION 2447)

CITY OF WASHINGTON
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The Lord Baltimore Press
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PRELIMINARY DIAGNOSES OF NEW MAMMALS
OBTAINED BY THE YALE-NATIONAL
GEOGRAPHIC SOCIETY PERU-
VIAN EXPEDITION

By OLDFIELD THOMAS, BRITISH MUSEUM

By arrangement with the authorities of the Yale-National Geographic Society Peruvian Expedition the United States National Museum has submitted to me for working out the very fine collection of mammals made by Mr. Edmund Heller during the year 1915. This material was obtained at localities lying between Lat. $12^{\circ} 30'$ and $13^{\circ} 30'$ S., Long. 72° and 73° W., in the region of Cuzco, Peru. The following are preliminary diagnoses of the new forms. A full account of the collection will be published in due course.

MICRORYZOMYS, subg. nov. of **ORYZOMYS**

Teeth very small. Zygomatic plate not projected forwards.

Genotype.—*Oryzomys minutus* Tomes.

ORYZOMYS (MICRORYZOMYS) AURILLUS, sp. nov.

Near *Oryzomys dryas*, but color duller and ears longer.

Head and body of type 83 mm.; tail 134; hindfoot 22.5; ear 15.5.

Skull, greatest length 23.5.

Habitat.—Torontoy.

Type.—Female. U. S. Nat. Mus. No. 194795; original number 255.

HESPEROMYS FRIDA, sp. nov.

Large, with comparatively long tail. Supraorbital ridges little divergent.

Head and body of type 102 mm.; tail 91; hindfoot 19; ear 18.

Skull, greatest length 26.7.

Habitat.—Chospayoc, 10,000 feet.

Type.—Female. U. S. Nat. Mus. No. 194779; original number 96.

HESPEROMYS CARILLUS MARCARUM, subsp. nov.

Duller colored than true *carillus*; tail white above; soles more hairy.

Head and body 82 mm.; tail 46; hindfoot 17.7. Upper molar series 3.7.

Habitat.—Lauramarca.

Type.—Brit. Mus. No. 3. 2. 9. 8. Coll. O. Garlepp.

THOMASOMYS NOTATUS, sp. nov.

Size medium. Dark dorsal stripe present. Metatarsus with dark patches.

Head and body 128 mm.; tail 155; hindfoot 27; ear 18.5. Skull greatest length 33.

Habitat.—Torontoy, 9,500 feet.

Type.—Male. U. S. Nat. Mus. No. 194548; original number 173.

THOMASOMYS GRACILIS, sp. nov.

Similar to *Thomasomys baxops* but smaller; about the smallest of the genus.

Head and body 82 mm.; tail 120; hindfoot 21.5; ear 16. Skull, greatest length 26.1.

Habitat.—Matchu Picchu, 12,000 feet.

Type.—Male. U. S. Nat. Mus. No. 194816; original number 321.

THOMASOMYS DAPHNE, sp. nov.

Size small; ears short. Incisors unusually thrown forward.

Head and body 92 mm.; tail 133; hindfoot 23.5; ear 16. Skull, greatest length 27.7.

Habitat.—Ocoyambamba Valley, 9,100 feet.

Type.—Female. U. S. Nat. Mus. No. 194902; original number 521.

AKODON SURDUS, sp. nov.

Allied to *Akodon mollis* but more stoutly built, and darker in color, without tinge of buffy.

Head and body 110 mm.; tail 80; hindfoot 22.5; ear 16. Skull, greatest length 28.

Habitat.—Huadquiña, 5,000 feet.

Type.—Male. U. S. Nat. Mus. No. 194663; original number 835.

CHREOMYS INORNATUS, sp. nov.

Near *Chreomys pulcherrimus*, but ears smaller and bullæ and special markings reduced.

Head and body 122 mm.; tail 80; hindfoot 24.5; ear 16. Skull, greatest length 30.

Habitat.—Ollantaytambo, 13,000 feet.

Type.—Female. U. S. Nat. Mus. No. 194685; original number 457.

MICROXUS TORQUES, sp. nov.

Near *Microxus minus*, but the zygomatic plate broader.

Head and body 102 mm.; tail 94; hindfoot 22.3; ear 17. Skull, greatest length 28.

Habitat.—Matchu Picchu, 10,000 feet.

Type.—Male. U. S. Nat. Mus. No. 194607; original number 276.

LAMA VICUGNA MENSALIS, subsp. nov.

Size slightly less than in true *vicugna* and teeth much smaller. Color more strongly fulvous.

Greatest length of skull 240 mm.; length of molars 45.

Habitat.—Peru and Bolivia; type from Incapirra, Junin, Peru, 17,700 feet.

Type.—Male. Brit. Mus. No. 97. 10. 3. 18. Coll. J. Kalinowski.

OROLESTES, gen. nov. (CENOLESTIDÆ)

Like *Canolestes*, but with various differences in dentition, of which the most noticeable is that the canine is short, double-rooted, and shaped like a premolar.

Genotype.—*Orolestes inca*, new species.

OROLESTES INCA, sp. nov.

Dark brown above, rather paler below. Size and general appearance about as in *Canolestes fuliginosus*.

Head and body 120 mm.; tail 108; hindfoot 22; ear 15. Greatest length of skull 33.

Habitat.—Torontoy, 14,000 feet.

Type.—Male. U. S. Nat. Mus. No. 194401; original number 248.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 68, NUMBER 5

NEW EAST AFRICAN PLANTS

BY
PAUL C. STANDLEY



(PUBLICATION 2477)

CITY OF WASHINGTON
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NEW EAST AFRICAN PLANTS

BY PAUL C. STANDLEY

The Smithsonian African Expedition of 1909-10, under the direction of Col. Theodore Roosevelt, was planned with the purpose of increasing the biological collections of the United States National Museum. While the attention of the expedition was devoted primarily to the larger mammals of the region traversed, collections were also secured of other animals and of plants. The plants were collected chiefly by the late Dr. Edgar A. Mearns, one of the naturalists of the party. Although Dr. Mearns was interested principally in birds, he obtained a large series of plants, consisting of over three thousand numbers, about 2,300 of these coming from British East Africa, 650 from Uganda, and 125 from the Belgian Congo.

It is to be regretted that Dr. Mearns's other duties did not permit him to devote more time to botanical collections, for by his long experience as a field botanist he was eminently qualified for such work. As naturalist of the Mexican Boundary Survey of 1892-93 he collected or had collected under his direction the largest and best representation ever obtained, consisting of several thousand numbers, of the flora of that part of the United States and Mexican boundary which extends from El Paso, Texas, to San Diego, California. Dr. Mearns secured also what is undoubtedly the largest series of plants ever obtained in the Yellowstone National Park, and in addition he collected extensively in the Philippines, Arizona, Florida, Rhode Island, Minnesota, and southern New York. All his collections are deposited in the U. S. National Museum, and probably no one person has contributed a larger number of plants to that institution.

Mr. Edmund Heller, also a naturalist of the Smithsonian African Expedition, secured a smaller collection of plants, most of them from localities not visited by Dr. Mearns. In addition, Mr. Heller accompanied the Paul J. Rainey African expedition of 1911-12, and in connection with his zoological collections obtained an interesting series of plants.

So far only a part of the East African botanical collections has been studied, but even this partial study indicates that the series is of unusual interest. This is notably true of the specimens obtained upon Mount Kenia, one of the three highest peaks of tropical Africa. It is expected that ultimately it will be possible to publish a complete report upon the botanical collections. The present paper consists of descriptions of some of the apparently new species segregated in the groups thus far studied. There are included also a number of necessary nomenclatorial transfers.

The writer is indebted to Mr. Spencer Le M. Moore of the British Museum for the description of the new heath of the difficult genus *Erica*.

RADICULA CRYPTANTHA (A. Rich.) Standley

Nasturtium cryptanthum A. Rich. Tent. Fl. Abyss. 1: 15. 1847

RADICULA INDICA (L.) Standley

Sisymbrium indicum L. Mant. Pl. 93. 1767

RUBUS KENIENSIS Standley, sp. nov.

Caules dense fulvo-pilosi, aculeis numerosis brevibus recurvatis armati; folia pinnata, 3-5-foliolata, stipulis linearibus vel lanceolatis, foliolo terminali ovali vel ovali-orbiculari, basi subcordato vel rotundato, apice acuto vel abrupte acuminato, foliolis lateralibus angustioribus petiolulatis, omnibus rugosis dentatis, supra sparse et breviter pilosis, subtus dense pilosis, venis subtus prominentibus et aculeatis; paniculae pauciflorae; sepala oblonga vel ovalia vel obovata, cuspidata; petala suborbicularia alba; drupae numerosae, siccae vel subsiccae, breviter pilosae, pyrenis rugosis.

Stems stout, brown, densely pilose with short fulvous eglandulose hairs, bearing numerous short stout compressed recurved spines; leaves pinnately 3 or 5-foliolate, the stout petioles 2.5-5 cm. long, armed, like the rachis, with numerous short stout recurved spines, densely short-pilose; stipules linear or lanceolate, about 1 cm. long, attenuate; terminal leaflet oval to ovate-orbicular, 6.5-9 cm. long, 4-6 cm. wide, subcordate or rounded at the base, acute to abruptly acuminate at the apex, on a petiolule 2-4 cm. long, the lateral leaflets slightly narrower than the terminal one, rounded or obtuse at the base, on petiolules 3-5 mm. long, all the leaflets firm, more or less rugose, finely and irregularly dentate, sparsely short-pilose on the upper surface, densely pilose beneath, at least when young, the

veins prominent beneath, the midvein armed with few or numerous short stout recurved spines; panicles few-flowered, 8-10 cm. long, the bracts lanceolate and entire or trilobate; pedicels 1-2 cm. long, densely pilose, armed with short slender recurved spines; sepals oblong, oval, or obovate, 1 cm. long, abruptly cuspidate, the tip 1-2 mm. long, densely sericeous-pilose on both surfaces with fulvous hairs; petals suborbicular, 12-14 mm. long, white, rounded and crenate at the apex; fruit about 1 cm. in diameter, the drupes numerous, dry or nearly so, short-pilose; pyrenes 3-3.5 mm. long, slightly compressed, rugose.

Type in the U. S. National Herbarium, no. 632297, collected on the western slopes of Mount Kenia, British East Africa, in the bamboo zone, altitude about 3,000 meters, September 28 to October 7, 1909, by E. A. Mearns (no. 2325). This specimen is in fruit, but a flowering branch of the same collection is mounted on sheet 632296. Here also belongs no. 1791, from the lower border of the bamboo zone, collected October 8 to 13.

The proposed species is related to *Rubus petitianus* A. Rich., a plant of the mountains of Abyssinia, which is distinguished by its much less pubescent leaves and very differently shaped sepals. It seems to agree with none of the other species described in recent years from the highlands of eastern tropical Africa.

RUBUS MEARNSII Standley, sp. nov.

Caules dense glanduloso-setosi, aculeis sparsis brevibus recurvatis armatis; folia pinnata, foliolis 3-5, ovatis vel oblongo-ovatis, basi rotundatis vel subcordatis, apice subabrupte acuminatis vel longe attenuatis, rugosis, crenato-dentatis, supra sparse et breviter pilosis, subtus breviter pilosis et ad venas prominentes glanduloso-setosis; inflorescentiae axillares et terminales, 1-3-florae; sepala ovata, longe acuminata vel attenuata, dense glanduloso-setosa, aculeata; fructus sepalis multo brevior, drupis numerosis, siccis, apice puberulentis, basi tomentosis.

Stems stout, densely glandular-setose with short setae tipped with reddish glands, armed with few short, stout, slightly recurved spines; leaves pinnately 5-foliolate, or the upper 3-foliolate, the stout petioles 3-6 cm. long, densely glandular-setose; leaflets ovate or oblong-ovate, 4.5-8 cm. long, 2.5-4 cm. wide, rounded or subcordate at the base, subabruptly acuminate to long-attenuate at the apex, somewhat rugose, finely crenate-dentate with apiculate teeth, sparsely short-pilose on the upper surface, glandular-setulose

beneath along the veins and short-pilose elsewhere, the veins prominent beneath, bearing a few short weak spines, the terminal leaflet rarely somewhat lobed, on a petiolule 5-14 mm. long, the lateral leaflets sessile, those of the upper pair smaller than those of the lower pair; flowering branches axillary and terminal, 1-3-flowered, the bracts 3-foliolate, the peduncles 2-2.5 cm. long, glandular-setose; sepals ovate, 1.5-2.5 cm. long, 6-8 mm. wide, long-acuminate or attenuate to a subulate tip, densely glandular-setose outside and armed with numerous slender spines, short-pilose within; petals not seen; fruit not more than half as long as the sepals, the drupes numerous, apparently dry, puberulent above, tomentose at the base, the pyrenes 3-4 mm. long, rugose.

Type in the U. S. National Herbarium, no. 631482, collected on the western slopes of Mount Kenia, British East Africa, in the giant heath zone, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1431).

The plant is related to *Rubus mauensis* Engler, described from Mau Mountain, not far from Mount Kenia. That species differs in its trifoliolate leaves, with leaflets about as broad as long, and in its narrower sepals.

RUBUS ROOSEVELTII Standley, sp. nov.

Caules juniores pilis laxis fasciculatis sparse tomentulosi, vetustiores glabrati, aculeis numerosis validis recurvatis armati; stipulae lineares ciliatae; folia palmata, 5-foliolata, foliolis petiolulatis, suborbicularibus usque obovato-ovalibus, basi rotundatis vel subcordatis, apice acutis vel breviter acuminatis, dentatis subcoriaceis rugosis, supra glabris vel sparse adpresso-pilosis, subtus minute glanduloso-puberulentis et ad venas prominentes adpresso-pilosis; paniculae terminales multiflorae, ramulis tomentulosi; sepala lanceolata-oblonga acuminata; petala obovata alba, sepalis dimidio longiora.

Stems reddish brown, the young ones very sparsely tomentulose with weak fasciculate hairs, soon glabrate, armed with numerous stout, short, compressed, strongly recurved spines; stipules linear, 10-12 mm. long, attenuate, ciliate; leaves palmately 5-foliolate, the petioles 2.5-4.5 cm. long, with pubescence and spines like those of the stems; petiolules 4-15 mm. long, fasciculate-pilose with fulvous hairs; leaflets suborbicular to oval, obovate-oval, or oval-ovate, 3-5.5 cm. long, 2-4 cm. wide, rounded or subcordate at the base, acutish to short-acuminate at the apex, finely dentate with narrow acute or mucronate teeth, thick and firm, strongly rugose, dark

green on the upper surface and glabrous or very sparsely appressed-pilose, slightly paler beneath, sparsely appressed-pilose along the veins and minutely glandular-puberulent, the veins very prominent beneath, the midvein armed with numerous slender, strongly recurved spines; panicles terminal, many-flowered, about 10 cm. long and 5 cm. wide, narrowly pyramidal, the branches densely tomentulose; bractlets linear, tomentulose; pedicels 5-10 mm. long, armed with slender recurved spines; sepals lance-oblong, 5-7 mm. long, acuminate, short-apiculate, densely tomentose with yellowish hairs; petals one and one-half times as long as the sepals, white, obovate, emarginate; fruit not seen.

Type in the U. S. National Herbarium, no. 632343, collected on the western slopes of Mount Kenia, British East Africa, in the bamboo zone, altitude about 3,000 meters, September 28 to October 7, 1909, by E. A. Mearns (no. 2371).

The writer is unable to find any previous report of a *Rubus* with palmate leaves from eastern Africa.

CHAMAECRISTA GRANTII (Oliver) Standley

Cassia grantii Oliver, Fl. Trop. Afr. 2: 279. 1871

CHAMAECRISTA KIRKII (Oliver) Standley

Cassia kirkii Oliver, Fl. Trop. Afr. 2: 281. 1871

CHAMAECRISTA MIMOSOIDES (L.) Standley

Cassia mimosoides L. Sp. Pl. 379. 1753

CHAMAECRISTA NIGRICANS (Vahl) Standley

Cassia nigricans Vahl, Symb. Bot. 1: 30. 1790

CHAMAECRISTA USAMBARENSIS (Taub.) Standley

Cassia usambarensis Taub. in Engl. Pflanzenw. Ost-Afrikas C: 201. 1895

INDIGOFERA MEARNSII Standley, sp. nov.

Frutex ramosus, ramis pilis fuscis dense puberulentis; stipulae lineari-subulatae; folia numerosa, internodiis multo longiora, foliolis 9-13, lateralibus oppositis, ovalibus vel ovali-oblongis, basi et apice rotundatis vel obtusissimis, mucronatis, supra strigillosis, subtus pallidis et densius strigillosis; racemi axillares vel terminales, dense multiflori; bracteae subulatae, calycem aequantes vel eo breviores; calyx fusco-puberulentus, lobis tubum aequantibus; legumina deflexa recta subteretia 7-8-sperma.

Erect shrub, much branched, the branches ascending, stout, dark brown or grayish brown, densely puberulent with dark brown hairs: stipules linear-subulate, 2-3 mm. long; leaves numerous, much longer than the internodes, the rachises 3-5 cm. long, shallowly sulcate on the upper side, densely brown-puberulent; leaflets 9-13, the lateral ones opposite, oval or oval-oblong, 9-20 mm. long, 4-8 mm. wide, rounded or very obtuse at each end, mucronate at the apex, rather firm, grayish green and strigillose on the upper surface, pale beneath and more densely strigillose; flowers partly in dense axillary racemes up to 10 cm. long, on peduncles 3 cm. long or shorter, but also in terminal racemes, these sometimes corymbose, the racemes very dense, many-flowered, the rachis densely brown-puberulent; bracts subulate, equaling or shorter than the calyx; pedicels 1-2 mm. long; calyx 2 mm. long, densely brown-puberulent, the lobes about as long as the tube; banner 5-7 mm. long, densely brown-sericeous outside; legumes deflexed, straight, subterete, 2.5-3.5 cm. long, acuminate at the apex, mostly 7-8-seeded, densely covered with short, closely appressed, dark brown hairs.

Type in the U. S. National Herbarium, no. 631040, collected in the vicinity of Nairobi, British East Africa, altitude about 2,000 meters, August 16 to September 3, 1909, by E. A. Mearns (no. 1004). Mearns's no. 958 from the same locality is this species, as well as no. 208, from Juja Farm, near Nairobi.

The proposed species is an ally of *Indigofera macrophylla* Schum., which differs in its large leaflets, long slender racemes, and glabrous legumes. It may be that *I. mearnsii* is the same as *I. oliveri* Schweinf.¹ That name was applied to a plant collected in the Masai Highlands near N'doro by Von Höhnelt, but no description has ever been published.

ERIOSEMA DICTYONEURON Standley, sp. nov.

Herba erecta, basi fruticosa, ramis validis striatis, pilis fuscis vel fulvis dense et breviter pilosis; stipulae lanceolatae; folia unifoliolata, petiolis brevissimis, laminis ovato-ovalibus vel late oblongo-ovatis, basi subcordatis, apice rotundatis vel late obtusis, subcoriaceis, supra rugulosis et sparse sericeis, subtus fulvo-sericeis, venis subtus prominentibus, reticulatis; racemi axillares et terminales, densi, bracteis ovatis vel lanceolatis; calyx 8-10 mm. longus, lobis linearibus, extus piloso-sericeis; legumina dense pilosa.

¹ Engl. Hochgebirgsflora Trop. Afr. 259. 1892.

Plants erect, fruticose at the base, sparsely branched, the branches erect or strongly ascending, stout, striate, densely short-pilose with fulvous or brown hairs; stipules lanceolate, 2-4 mm. long, brown, densely pilose-sericeous outside; leaves simple, the petioles very stout, about 2 mm. long; leaf blades ovate-oval or broadly oblong-ovate, 2.5-4 cm. long, 1.6-2.8 cm. wide, subcordate at the base, rounded or broadly obtuse at the apex, subcoriaceous, rugulose on the upper surface and thinly sericeous with short hairs, sericeous beneath with short fulvous hairs, very prominently veined beneath, the lateral veins about 5 on each side, the secondary veins coarse, closely reticulate; flowers in short axillary racemes and in dense terminal racemes up to 5 cm. long; bracts ovate or lanceolate, 3 to 4 mm. long, densely pilose; pedicels 2 to 8 mm. long; corolla not seen; calyx 8 to 10 mm. long, the tube very short, the lobes linear, attenuate, pilose-sericeous outside; legume about 2 cm. long, 7-8 mm. wide, obtuse or acute, mucronate, 2-seeded, densely pilose with long brown hairs; seeds 3.5-4 mm. long, finely spotted with brown and black.

Type in the U. S. National Herbarium, no. 631103, collected between Thika and Fort Hall, British East Africa, altitude 1,200 to 1,500 meters, September 3 to 9, 1909, by E. A. Mearns (no. 1067).

Distinguished from the other African species with simple leaves by the broad, coriaceous, reticulate-veined leaf blades.

GERANIUM KENIENSE Standley, sp. nov.

Caules graciles, procumbentes, dense et minute viscido-puberuli; folia opposita petiolata, laminis angulata-orbicularibus 5-7-lobatis, lobis late cuneatis 5-dentatis, minute puberulis et sparse setoso-pilosis; pedunculi 1-flori; sepala anguste oblonga vel lanceolato-oblonga, acuminata; petala late obovata purpurascencia; fructuus rostrum breviter hirtellum, valvulis hirsutis.

Stems slender, procumbent, 20-30 cm. long, densely and minutely viscid-puberulent, the internodes 3.5-9 cm. long; cauline leaves opposite, the slender petioles 3.5-12 cm. long, minutely viscid-puberulent and sparsely pilose; leaf blades angulate-orbicular, 2.5-4 cm. broad, 5-7-lobed two-thirds the distance to the base, the lobes broadly cuneate, usually 5-dentate, the teeth oval-oblong or ovate, obtuse or acutish, the blades rather firm, minutely puberulent and sparsely setose-pilose with appressed hairs; stipules oval-ovate.

5-6 mm. long, 3 mm. broad, acute or acuminate, membranaceous, minutely puberulent and sparsely pilose; peduncles 5-6.5 cm. long, slender, 1-flowered, the bracts lanceolate, 2.5-3 mm. long; pedicels minutely viscid-puberulent; sepals narrowly oblong or lance-oblong, 6-7 mm. long, acuminate, mucronate, densely and minutely puberulent and sparsely short-pilose, the mucro 1 mm. long; petals broadly obovate, purplish, 8 mm. long; fruit (immature) 15 mm. long, the beak short-hirtellous and puberulent, the valves hirsute.

Type in the U. S. National Herbarium, no. 631573, collected on the western slopes of Mount Kenia, along the trail from West Kenia Forest Station to summit, in the giant heath zone, British East Africa, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1513).

The proposed species is doubtless most closely related to *Geranium simense* Hochst. That species, however, is clearly distinguished by its very different pubescence, which is composed of long, slender, reflexed hairs, without any trace of the minute puberulent pubescence characteristic of *G. kenienne*. There is a difference also in leaf outline, the blades in *G. simense* being more deeply lobed and uniformly with 5 divisions.

MONSONIA PUMILA Standley, sp. nov.

Herba perennis, erecta vel adscendens, caulibus dense cinereis; folia opposita, petiolis laminis aequilongis, laminis rhombeo-ovatis, apice obtusis vel rotundatis, basi truncatis vel rotundatis, crenulatis, crispatis, supra glabris, subtus ad venas cinereis; pedunculi 1-2-flori; sepala lineari-oblonga, minute glandulosa et albo-hirsuta; petala late cuneato-obovata integra.

Plants erect or ascending, 4-6 cm. high, perennial from a thick branched caudex; stems stout, sparsely branched, very densely cinereous, the pubescence short, coarse, appressed; leaves cauline, opposite, the petioles about equaling the blades, cinereous; stipules linear-setaceous, 4-7 mm. long, white-hirsute; leaf blades rhombic-ovate, 8-16 mm. long, obtuse or rounded at the apex, truncate or rounded at the base, crenulate, crispate, very thick, glabrous above, cinereous beneath along the veins; peduncles 1-2-flowered, 1-1.8 cm. long, cinereous, the bracts linear-lanceolate; sepals linear-oblong, 1 cm. long, finely glandular and white-hirsute, the broad margins membranaceous, the mucro 1.5 mm. long; petals 1.5 cm. long, apparently purplish, broadly cuneate-obovate, entire; fruit (immature) appressed-hirsute.

Type in the U. S. National Herbarium, no. 630563, collected on the Southern N'guaso Nyiro River, "Sotik Country," British East Africa, altitude 1,800 to 2,100 meters, July 1 to 3, 1909, by E. A. Mearns (no. 540).

Although the specimens are only in flower, it is evident from their general appearance that they belong to the section *Plumosae*.¹ The proposed species seems to be related to *Monsonia longipes* Knuth, described from Makindu, British East Africa, but that is a very different plant in stature and pubescence.

VIOLA MEARNSII Standley, sp. nov.

Herba perennis, decumbens vel prostrata, caulibus gracilibus, retrorse hirtellis; stipulae ovatae usque lineari-lanceolate, laciniato-lobatae punctatae ciliatae; folia petiolata, laminis suborbicularibus vel reniformi-orbicularibus, apice late rotundatis, basi subcordatis vel truncatis, crenatis, ad venas minute hirtellis, subtus punctatis; sepala anguste lanceolato-oblonga ciliata; petala caerulea.

Decumbent or prostrate perennial, much branched, the branches slender, brownish, finely retrorse-hirtellous with white hairs; stipules thin, green, ovate to narrowly oblong or linear-lanceolate, 4-6 mm. long, acuminate to attenuate, ciliate, brown-punctate, laciniately lobed; petioles slender, 0.5-2 cm. long, retrorse-hirtellous; leaf blades suborbicular or reniform-orbicular, 7-18 mm. broad, broadly rounded at the apex, subcordate or truncate at the base, finely crenate, ciliate, minutely hirtellous on the upper surface along the veins, paler beneath and brown-punctate, retrorse-hirtellous along the veins; peduncles axillary, 1-6.5 cm. long, retrorse-hirtellous, bracteate at about the middle, the bracts lance-linear; sepals narrowly lance-oblong, 5-6 mm. long, ciliate; petals blue, 6-8 mm. long, the spur 2-2.5 mm. long and nearly as thick; capsules 5 mm. long, brown-punctate; seeds oval, 1.8 mm. long, pale brown, smooth.

Type in the U. S. National Herbarium, no. 631672, collected in the bamboo zone, western slopes of Mount Kenia, along the trail from West Kenia Forest Station to summit, British East Africa, altitude about 3,000 meters, September 28 to October 7, 1909, by E. A. Mearns (no. 1718). Mearns's no. 1754 from the same locality is also this species; likewise his no. 1344, which was collected in the giant heath zone at an altitude of about 3,630 meters.

Very probably this plant is the one described by Engler as *Viola abyssinica eminii*, from Mount Kilimanjaro and Mount Ruwenzori.

¹ Knuth in Engl. Pflanzenreich 53: 293. 1912.

His description, however, is too incomplete to be certain. *Viola mearnsii* is a near relative of *V. abyssinica* Steud. but the latter is well distinguished by the narrower, acute leaves, narrow stipules, larger capsules and flowers, and especially by the spreading pubescence.

ERICA KENIENSIS S. Moore, sp. nov.

Fruticulus glaber ramulis elongatis erectis apice floriferis, foliis suboppositis nisi alternis satis dense erecto-imbricatis subsessilibus angustissime lineari-lanceolatis breviter acuminatis glabris pagina superiore planis pagina inferiore carinatis, floribus tetrameris in foliorum summorum axillis solitariis pedicellis juxta medium bibracteolatis quam corolla plane brevioribus fultis, calycis segmentis erectis basi latis sursum lanceolatis acuminatis corollam fere semiaequantibus, corollae urceolatae lobis rotundatis obtusissimis, staminibus 8 filamentis paullo supra basin antherarum dorsifixis antheris quadrato-oblongis loculis superne liberis obtusis basi curvato-aristatis, ovario globoso quam stylus inclusus brevior.

TABLE I

	Leaves	Pedicels	Bracteoles	Calyx and Corolla	Anthers
<i>Whyteana</i>	Frequently in verticels or subverticels of 4.	3 mm. long.	Rather more than 1 mm. long.	Calyx segm'ts reflexed. Corolla tube 3.5 × 3 mm.	Oblong throughout, 0.7 mm. long.
<i>Swynnertonii</i> ..	Usually in verticels or subverticels of 3.	6-7 mm. long.	3-4 mm. long.	Calyx segm'ts reflexed. Corolla tube 4 × 3.5 mm.	Narrowed above, 1 mm. long.
<i>Keniensis</i>	Usually subopposite or alternate.	2 mm. long.	1.5 mm. long.	Calyx segm'ts erect. Corolla tube 5.5 × 3.5 mm.	Not narrowed above, 1 mm. long.

Hab. British East Africa, Mt. Kenia, bamboo zone, from West Kenia Forest Station to summit, at about 3,000 meters, *E. A. Mearns* 1734. Type in the Herbarium of the British Museum.¹

Planta bispithamea. Folia pleraque 6-7 mm. long., 0.75-1 mm. lat., crassiuscula, in sicco brunnea. Pedicelli 2 mm. long.; bracteolae anguste lineares, 1.5 mm. long. Calycis segmenta 2.5 mm. long., margine microscopice ciliolata. Corolla rosea, in toto 5.5 mm. long., 3.5 mm. lat. Filamenta 3 mm. long., antherae 1 mm.

¹ Mearns's nos. 1485, 1662, and 1767, from Mt. Kenia, are also this species.—P. C. S.

Ovarium 1 mm. diam., subprofunde 8-sulcatum; ovula in loculo plura. Stylus 2.75 mm. long.

The affinity of this is with the Southern Tropical montane species *E. whyteana* Britten and *E. swynnertonii* S. Moore. The chief differences between the three are as in Table I.

ASTROCHLAENA MENISPERMOIDES Standley, sp. nov.

Caules graciles prostrati, pilis fulvis stellato-pubescentes; foliorum laminae ovato-orbiculares vel rhombeo-orbiculares vel summae late rotundato-ovatae, apice late rotundatae vel obtusae, basi truncatae usque subcordatae, integrae, pilis brevibus stellatis pubescentes; pedunculi plerumque 3-flori, bracteis linearibus; sepala oblonga vel anguste oblonga, exterioribus obtusis, dense stellato-pubescentibus, interioribus acutis, costa excepta glabris; corolla glabra; capsulae glabrae; semina dense et minutissime puberulae.

Stems slender, prostrate, about 1 meter long, branched, stellate-pubescent with fulvous hairs; petioles slender, 0.5-2 cm. long; leaf blades ovate-orbicular or rhombic-orbicular, or the uppermost broadly rounded-ovate, 1.5-2.8 cm. long, 1.4-3.5 cm. wide, usually broader than long, broadly rounded to obtuse at the apex, truncate or subcordate at the base, entire, stellate-pubescent on both surfaces with fulvous hairs; peduncles axillary, slender, 1.5-2.8 cm. long, mostly 3-flowered, the bracts linear, 2-3 mm. long, the pedicels 5-10 mm. long, recurved in age; sepals 8-10 mm. long, oblong or narrowly oblong, the outer obtuse, densely stellate-pubescent, the inner acute, glabrous except along the costa; corolla about 3.5 cm. long, glabrous, the tube 4-5 mm. in diameter; capsule 7-9 mm. in diameter, glabrous; seeds densely and very minutely pubescent.

Type in the U. S. National Herbarium, no. 630249, collected in the vicinity of Nairobi, British East Africa, altitude about 2,000 meters, May 26 to June 1, 1909, by E. A. Mearns (no. 236).

Readily distinguished from the other East African species by the broad, small leaf blades, associated with the long, prostrate stems. The corolla appears to be rose purple.

CONVOLVULUS KENIENSIS Standley, sp. nov.

Caules herbaceae, scandentes, pilis brevissimis patulis fulvis pilosae; folia petiolata, laminis late cordato-ovatis vel triangulari-ovatis, interdum subhastatis, apice acutis usque acuminatis, basi leviter vel profunde cordatis, lobis basalibus rotundatis vel angulatis, integris, junioribus dense piloso-sericeis, vetustioribus sparse

et breviter pilosis; pedunculi multiflori, apice bracteis 2 foliaceas gerentes, floribus capitatis, capitibus solitariis vel pluribus, bracteis floralibus late ovalibus vel suborbicularibus, calycem aequantibus vel excedentibus; sepala late ovata usque suborbicularia, scariosa; corolla campanulata alba; ovarium glabrum.

Stems herbaceous, scandent, slender, pilose with very short spreading fulvous hairs; petioles 0.6-3 cm. long; leaf blades broadly cordate-ovate or deltoid-ovate, sometimes subhastate, 3-8 cm. long, 2.3-6 cm. long, acute to acuminate at the apex, shallowly or deeply cordate at the base, the lobes rounded or angulate, thin, entire or slightly undulate, densely pilose-sericeous when young with fulvous hairs, thinly short-pilose in age; peduncles 2-10 cm. long, many-flowered, bearing at the apex 2 leaflike bracts, the flowers numerous, capitate, the heads 1 or several, the pedicels 5 mm. long or shorter, the bracts subtending the flowers broadly oval or suborbicular, equaling or exceeding the calyx, obtuse or abruptly short-cuspidate, short-pilose; sepals 10-13 mm. long, 10 mm. wide or narrower, broadly oval, ovate-oval, or suborbicular, scarious, the outer ones pilose with very short fulvous hairs; corolla campanulate, 2.8 cm. long, white, the margin dentate, densely sericeous in bud; filaments about 1 cm. long, short-pilose below; style as long as the filaments, the 2 stout filiform styles 3 mm. long; ovary glabrous.

Type in the U. S. National Herbarium, no. 631345, collected on the western slopes of Mount Kenia, British East Africa, in the giant heath zone, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1294).

Related, apparently, to *Convolvulus kilimandschari* Engler, a plant with longer pubescence, obtuse leaf blades, and acute bracts.

EHRETIA INAMOENA Standley, sp. nov.

Rami juniores hirsuti, vetustiores glabrescentes; folia petiolata, laminis ovalibus usque ovali-obovatis, basi subcordatis usque obtusis, apice obtusis usque acuminatis, integris, supra glabris vel ad costam sparse hirtellis, subtus sparse hirsutis vel hirtellis; paniculae terminales, dense multiflorae, ramulis breviter pilosis; calyx 5-lobatus, ferrugineo-puberulus, lobis ovatis acutis; corolla glabra, tubo 3 mm. longo, lobis ovalibus, apice rotundatis, 2-3 mm. longis; stamina exserta; fructus 4-lobatus.

Branches stout, brownish, hirsute when young with rather short slender stiff whitish hairs, glabrate in age; petioles 0.8-1.8 cm. long, hirsute; leaf blades oval, oval-obovate, or oval-oblong, 5.5-12

cm. long, 2.5-6.5 cm. wide, subcordate to obtuse at the base, obtuse to acuminate at the apex, sometimes abruptly acuminate, entire, thin, glabrous on the upper surface or sparsely hirtellous along the midvein, thinly hirsute or hirtellous beneath, the veins impressed on the upper surface, prominent beneath, the secondary ones laxly reticulate; panicle terminal, up to 12 cm. broad, many-flowered, dense, the branches densely short-hirsute; calyx 5-lobed, 2 mm. long, ferrugino-puberulent, the lobes ovate, acute, minutely ciliate; corolla tube 3 mm. long, glabrous, the lobes 2-3 mm. long, oval, rounded at the apex, ciliate; stamens exserted, inserted in the corolla throat; style long-exserted, divided one-fourth its length; fruit 5-6 mm. in diameter, 4-lobed.

Type in the U. S. National Herbarium, no. 631940, collected along the trail from Nyeri to Wambugu, British East Africa, altitude 1,500 to 1,800 meters, October 21 to 25, 1909, by E. A. Mearns (no. 1981). Nos. 1939 and 1970 from the same region also represent this species.

The proposed species is related to *Ehretia abyssinica* R. Br., but that has nearly or quite glabrous leaves and a lax, less pubescent inflorescence, as well as a larger corolla.

ACHYROSPERMUM MEARNsii Standley, sp. nov.

Caules subteretes, dense fulvo-pilosi; folia petiolata, laminis ovalibus vel ovali-ovatis, apice abrupte et breviter acuminatis, basi abrupte ad petiolum gracilem decurrentibus, tenuibus, crenatis, sparse pilosis, subtus punctatis; racemi spiciformes densi; bracteae latae, apice late rotundatae et apiculatae, longe ciliatae; calyx pilosus, lobis ovatis apiculatis, tubo multo brevioribus; corolla parva, extus pilosa vel puberula.

Stems very stout, subterete, densely fulvous-pilose or finally glabrate; leaf blades oval or oval-ovate, 5-10 cm. long, 3-7 cm. wide, abruptly short-acuminate at the apex, abruptly decurrent at the base to a slender petiole, the lower naked part of the petiole 7-15 mm. long, densely pilose, the blades thin, crenate, rather sparsely pilose, slightly paler beneath and finely punctate; inflorescence terminal and on short weak lateral branches, the racemes spicate, very dense, 2-6 cm. long, about 2 cm. thick; bracts about 6 mm. long and 10 mm. broad, broadly rounded at the apex and apiculate, long-ciliate; pedicels about 1 mm. long; calyx 6 mm. long, pilose, the lobes ovate, apiculate, much shorter than the tube; corolla 8-9 mm. long, pilose or puberulent outside.

Type in the U. S. National Herbarium, no. 631392, collected on the western slopes of Mount Kenia, British East Africa, in the giant heath zone, altitude 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1343). No. 1321 from the same locality also is this plant. Two other collections belong here: no. 1214 from the vicinity of Fort Hall, altitude 1,200 meters; and no. 1992, collected on the trail from Nyeri to Wambugu, altitude 1,500 to 1,800 meters. In view of the remarkable altitudinal range it may be that the specimens purporting to come from Mount Kenia are really from some other locality.

The proposed species seems to be near *Achyrospermum parviflorum* S. Moore, but that has different pubescence and short racemes. It is said, also, to have red corollas, while in *A. mearnsii* these seem to be white.

COLEUS KENIENSIS Standley, sp. nov.

Caules herbacei, puberuli vel sparse et breviter villosi, plus minusve glandulosi; folia longe petiolata, laminis ovato-deltaideis, basi truncatis, apice acutiusculis usque acuminatis, crenatis, copiose glandulosis et sparse villosulis; inflorescentia terminalis, racemis laxis, cymis 3-floris, longe pedunculatis, bracteis parvis persistentibus; calyx minute glanduloso-puberulus, lobis anguste triangularibus, acutis vel acuminatis; corolla 1.5 cm. longa.

Stems herbaceous, apparently scandent or recumbent, puberulent or thinly short-villous and more or less glandular; petioles slender, 2-6.5 cm. long; leaf blades ovate-deltoid, 2.5-5 cm. long, 2-4 cm. wide, truncate at the base, acutish to acuminate at the apex, coarsely but regularly crenate, thin, bright green, copiously glandular and sparsely short-villous on both surfaces; inflorescence terminal, racemose, 8-12 cm. long, 4-6 cm. broad, very lax, the cymes 3-flowered, on peduncles 1-2 cm. long, the pedicels slender, 5-8 mm. long, densely glandular-puberulent; bracts small, foliaceous, persistent; calyx in flower 2.5 mm. long, in fruit 4-5 mm. long, minutely glandular-puberulent, naked inside, the teeth narrowly triangular, acute or acuminate; corolla about 1.5 cm. long, puberulent or sparsely short-villous outside, the tube slender, several times longer than the calyx, the lower lip about 9 mm. long.

Type in the U. S. National Herbarium, no. 631384, collected on the western slopes of Mount Kenia, British East Africa, in the giant heath zone, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1334). The species is represented also

by no. 1287 from the same locality, and by nos. 1780 and 1797 from the lower border of the bamboo zone, altitude about 2,550 meters.

SOLANUM HELLERI Standley, sp. nov.

Frutex, ramis dense et minute stellato-tomentulosis, aculeis numerosis validis compressis recurvatis dense stellato-tomentosis armatis; folia breviter petiolata, laminis late ovatis, basi rotundatis vel subcordatis, apice acutiusculis usque acuminatis, integris vel undulatis, coriaceis, glabris vel pilis sparsis minutis stellatis onustis, ad costam et supra et subtus aculeis validis fulvis rectis 1 vel pluribus armatis; flores solitariae vel geminatae vel laxae cymosae, pedicellatae; calyx ad basin minute stellato-pubescent, aculeis numerosis armatus, aetate paulo accrescens, lobis ovalibus; corolla rotata, lobis anguste lanceolato-triangularibus, acuminatis; fructus juventute minute stellato-pubescent, mox glabrescent.

Shrub, the branches spreading, stout, very densely and finely stellate-tomentulose with yellowish white hairs, armed with numerous spines, these very stout, compressed, recurved, densely stellate-tomentulose, 8-13 mm. long, 6-10 mm. broad at the base; petioles stout, 2-5 mm. long; leaf blades broadly ovate, about 2 cm. long, rounded or subcordate at the base, acutish to acuminate at the apex, entire or undulate, coriaceous, bright green, glabrous or bearing a few remote minute stellate hairs, armed on the midrib on each side with 1 to several stout straight yellowish spines 0.5-1.5 cm. long; flowers solitary or geminate or in slender few-flowered racemose cymes, the pedicels 5-10 mm. long, sometimes armed with spines like those of the stems; calyx campanulate, 6 mm. long, finely stellate-pubescent at the base, armed with numerous stout straight spines 4-10 mm. long, slightly accrescent in age and partially inclosing the fruit, the lobes oval, rounded at the apex; corolla rotate, about 2.5 cm. broad, the lobes narrowly lance-triangular, acuminate, 4 mm. broad at the base, densely and finely stellate-pubescent outside; anthers 7-8 mm. long; fruit (immature) globose, 8 mm. in diameter, finely stellate-pubescent when young, early glabrate.

Type in the U. S. National Herbarium, no. 634351, collected on the Northern Guaso Nyiro, British East Africa, September 26, 1911, by Edmund Heller.

The plant is said to be an abundant shrub, forming thickets. It seems to be very different from the East African species heretofore described.

SOLANUM KENIENSE Standley, sp. nov.

Caules scandentes, inermes, juventute pilis hispidulis vel laxe ramulosis fulvo-tomentosi, glabrescentes; folia petiolata, laminis ovali-ovatis vel rotundato-ovatis, apice obtusis vel breviter acuminiatis, basi truncatis vel late rotundatis, subcoriaceis, integris, supra sparse, subtus dense pilis fulvis, ramulosis vel hispidulis praeditis; cymae multiflorae, paniculas terminales formantes; calyx 5-lobatus, stellato-tomentosus, lobis tubum aequantibus, triangulari-ovatis; corollae lobi deltoidei, acuti.

Stems scandent, subangulate, unarmed, when young fulvous-tomentose with long, matted, hispidulous or loosely branched hairs, soon glabrate; petioles 1-2 cm. long, densely tomentose like the stems; leaf blades oval-ovate or rounded-ovate, 3.5-9 cm. long, 2.5-6.5 cm. wide, obtuse or short-acuminate at the apex, truncate or broadly rounded at the base, subcoriaceous, entire, grayish green on the upper surface and sparsely furnished, especially along the impressed nerves, with short, brown, stellate or hispidulous hairs, beneath densely covered with long, brownish, stalked, branched or hispidulous hairs, the pubescence persistent; cymes many-flowered, arranged in a terminal divaricate panicle 8 cm. long and broad, densely tomentose; pedicels 8 cm. long; calyx 3 mm. long, 5-lobed, densely stellate-tomentose outside, the lobes about as long as the tube, deltoid-ovate, obtuse or acutish; corolla 12-15 mm. broad, finely stellate-pubescent outside, the lobes deltoid, acute or acutish; stamens 5, shorter than the corolla tube; fruit not seen.

Type in the U. S. National Herbarium, no. 631465, collected in the giant heath zone, western slopes of Mount Kenia, British East Africa, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1416).

A very distinct species, apparently, and from an unusually high altitude for a plant of this genus.

BARTSIA KENIENSIS Standley, sp. nov.

Caules robusti, minute puberuli vel glabrati; foliorum laminae anguste lanceolato-oblongae, apice obtusae vel rotundatae, basi cuneatim in petiolum brevem angustatae, crenatae, glabrae vel supra obscure scaberrulae; calyx minute glanduloso-puberulus, fere aequaliter 4-lobatus, lobis tubum aequantibus, oblongis, obtusissimis, apice crenatis; corollae tubus curvatus, limbus bilabiatus, labio superiore galeato, labio inferiore profunde 3-lobato, lobis obovato-orbicularibus; ovarium dense sericeum.

Stems terete, stout, about 3 mm. in diameter, minutely puberulent or glabrate; leaves numerous, rather crowded, the internodes 1-1.5 cm. long; leaf blades narrowly lance-oblong, 3.5-5 cm. long, 6-10 mm. wide, obtuse or rounded at the apex, cuneately narrowed at the base into a very short marginate petiole, thick and firm, flat, crenate, glabrous, or obscurely scaberulous on the upper surface, the leaves of the inflorescence only slightly smaller than the lower ones; pedicels 1-2 mm. long; calyx 13-16 mm. long, minutely glandular-puberulent, almost equally 4-lobed, the lobes as long as the tube, oblong, very obtuse, crenate about the apex; corolla tube 2.5 cm. long, 2 mm. in diameter, curved, minutely glandular-puberulent, the limb bilabiate, the upper lip galeate, sparsely villous inside, 6-7 mm. long, the lower lip deeply 3-lobed, the lobes obovate-orbicular, 8 mm. long, crenate; stamens attached near the top of the tube, the anthers mucronate at the base, sparsely bearded; ovary densely sericeous.

Type in the U. S. National Herbarium, no. 631542, collected on the western slopes of Mount Kenia, British East Africa, in the giant heath zone, altitude about 3,630 meters, September 21 to 27, 1909, by E. A. Mearns (no. 1487). No. 1426 from the same locality is also this species.

Related to *Bartsia kilimandscharica* Engler, which differs in its small leaves and flowers. *B. keniensis* is a shrub which blackens when dried. The four branches of the specimens are practically simple, but slender, weak, sterile branches are borne in the axils of some of the leaves.

RHAMPHICARPA TENUISECTA Standley, sp. nov.

Caules graciles, bifarie puberuli et pilis sparsis brevibus antrorse curvatis praediti; folia breviter petiolata, laminis pinnatifidis vel bipinnatifidis, segmentis anguste linearibus, scaberulis; flores in axillis superioribus solitariae, pedicellatae, bracteolis lineari-filiformibus; calyx scaber, lobis lanceolato-linearibus vel lineari-subulatis, tubum fere aequantibus; capsulae obliquae, calycem aequantes vel paulo superantes, acuminatae.

Stems erect or ascending, simple, 40-50 cm. long, very slender, bifariously puberulent, bearing also a few short, upwardly recurved hairs; internodes 2.5-7 cm. long; petioles about 2 mm. long; leaf blades 1.5-2.5 cm. long, pinnatifid or bipinnatifid into rigid, narrowly linear segments about 0.5 mm. wide, the segments acute, scaberulous; flowers solitary in the upper axils, on pedicels 2-4 mm. long;

bractlets linear-filiform, half as long as the calyx; calyx 1 cm. long, scabrous, the lobes lance-linear or linear-subulate, nearly as long as the tube; corolla tube 2 cm. long, minutely puberulent, the limb 5-6 mm. long; capsule oblique, equaling or slightly longer than the calyx, acuminate; seeds coarsely tuberculate.

Type in the U. S. National Herbarium, no. 632310, collected on the western slopes of Mount Kenia, British East Africa, in the bamboo zone, altitude about 3,000 meters, September 28 to October 7, 1909, by E. A. Mearns (no. 2338). No. 2328 from the same region also represents this species.

In general characters this plant is related to *Rhamphicarpa meyeri-johannis* Engler, described from Kilimanjaro, but that has more copious pubescence and shorter, triangular calyx lobes.

JUSTICIA ROOSEVELTII Standley, sp. nov.

Frutex dense ramosus, ramis dense cinereo-puberulis; folia numerosa, sessilia vel subsessilia, laminis parvis, oblongo-lanceolatis, apice acutis vel acutiusculis, basi obtusis, integris, dense cinereo-puberulis, coriaceis; flores axillares et solitariae, subsessiles, bracteis subulatis, medium calycis vix aequantibus; calyx dense puberulus, lobis lanceolato-subulatis; corolla rosea, 1 cm. longa, extus dense puberula; capsulae cinereo-puberulae, seminibus 4.

Shrub about 30 cm. high, fruticose nearly throughout, intricately branched, the branches stout, densely cinereo-puberulent, whitish; leaves numerous, sessile or subsessile, the blades oblong-lanceolate, 3-6 mm. long, 1-1.4 mm. broad, acute or acutish at the apex, obtuse at the base, entire, densely cinereo-puberulent or in age subglabrate, coriaceous, the margins often slightly revolute; flowers axillary, solitary, subsessile; bracts subulate, less than half as long as the calyx; calyx 3-4 mm. long, the lobes lance-subulate, densely cinereo-puberulent; corolla 1 cm. long, rose-colored, densely cinereo-puberulent outside; anthers hirtellous, the lower cell long-caudate; capsule 6 mm. long, densely cinereo-puberulent; seeds 4, coarsely tuberculate.

Type in the U. S. National Herbarium, no. 630746, collected along the Southern N'guaso Nyiro River, "Sotik Country," British East Africa, altitude 1,800 to 2,100 meters, July 24 to 30, 1909, by E. A. Mearns (no. 721). No. 524 from the same region is also this species.

Related, apparently, to *Justicia urbaniana* Lindau, of Somaliland, but differing conspicuously in pubescence as well as in size of flowers.

SAMBUCUS AFRICANA Standley, sp. nov.

Caules juniores minute villosuli, vetustiores glabrati; folia plerumque 5-7-foliolata, foliolis brevissime petiolulatis, serratis, supra glabris vel ad venas obscure puberulis, subtus sparse puberulis, lateralibus oblongis vel lanceolato-oblongis, basi oblique rotundatis, ad apicem abrupte acuminatum vel attenuatum angustatis, foliolo terminali ovato; inflorescentia cymosa, ampla, ramulis dense ferrugineo-villosulis; drupae magnae, pyrenis 3, angustis.

Stems minutely villosulous when young, glabrate in age, the internodes short; leaves numerous, usually 5-7-foliolate, the petioles 4-8 cm. long, the rachis 4-12 cm. long or longer; leaflets very shortly petiolulate, the lateral ones narrowly oblong or lance-oblong, 8.5-13 cm. long, 2.5-4.5 cm. wide, obliquely rounded at the base, narrowed to an abruptly acuminate or attenuate apex, the terminal leaflet ovate, rounded at the base, long-acuminate at the apex, all thin, sharply and finely serrate, glabrous on the upper surface or obscurely puberulent along the veins, sparsely puberulent beneath; inflorescence cymose, flat-topped, at anthesis about 7 cm. broad and very dense, in fruit 8-15 cm. broad, the branches densely ferrugineo-villosulous; pedicels very short, stout; calyx lobes ovate, acute or acutish, about 1 mm. long; corolla 4 mm. long; fruit about 7 mm. in diameter, the 3 nutlets 4-4.5 mm. long, 1.5 mm. broad.

Type in the U. S. National Herbarium, no. 631698, collected in the bamboo zone, western slopes of Mount Kenia, British East Africa, altitude about 3,000 meters, September 28 to October 7, 1909, by E. A. Mearns (no. 1746). No. 1731 from the same region is also this species. Two other collections also belong here: no. 832, from the vicinity of Lake Naivasha, altitude 1,860 to 1,950 meters; and no. 1898, collected along the trail from the Kasorongai River to the Katheroni River, altitude 1,800 to 1,950 meters. It seems probable that the last two specimens are wrongly labeled.

The only previous report of a *Sambucus* from tropical East Africa is found in Engler's *Pflanzenwelt Ost-Afrikas*.¹ That writer lists a single specimen from Abori, which he refers to *S. ebulus*, the common species of Europe which occurs also in Algeria. Concerning his material Engler says: "The occurrence in Abori is most surprising; but the plant agrees wholly with our species, even to the ovaries which are metamorphosed and enlarged, doubtless as the result of insect work."

¹ C: 374. 1895.

The ample material before the present writer represents a plant differing from *Sambucus ebulus* in at least two important respects: the branches of the inflorescence are pubescent rather than glabrous, as in that species, and the nutlets are about twice as long and much narrower proportionally. The difference in size of fruit is not the result of insect work, the drupes appearing quite normal.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
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MELIACEAE CENTRALI-AMERICANAE
ET PANAMENSES

BY
C. DE CANDOLLE



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MELIACEAE CENTRALI-AMERICANAE ET
PANAMENSES¹

AUCTORE C. DE CANDOLLE, GENEVA

GUAREA L.

1. **GUAREA BREVIANTHERA** C. DC. n. sp.

Ramulis glabris cinerascentibus ; foliis breviter petiolatis 3-4-jugis ; foliolis oppositis elliptico-lanceolatis basi aequilatera acutis apice obtusiuscule acuminatis utrinque glabris, rhachi minutissime puberula ; panicula axillari quam folium multo brevior brevisime pedunculata glabra, inferne brevissime ramulosa et superne spicatum cymuligera ; floribus longiuscule pedicellatis glabris ; calice 4-dentato, dentibus rotundatis summo apice acute apiculatis ; petalis 4 oblongis apice attenuato-acutis ; tubo stamineo cylindrico infra apicem paullo contracto margine leviter crenulato, antheris 8 minutis ovatis basi affixis ; ovario rotundato glabro.

Parva arbor. Folia alterna, usque ad 15 cm. longa. Foliola in sicco firma, supra nitentia, supera usque ad 14.5 cm. longa et 5.5 cm. lata, nervi secundarii subadscendentes subrecti utrinque circiter 7, rhachis supra sulcata. Petiolus 1.5-2.5 cm. longus. Paniculae florentes circiter 7 cm. longae, ramuli usque ad 1 cm. longi, florum pedicelli fere 2 mm. longi, petala in sicco atro-rubescencia 5 mm. longa et 1.5 mm. lata, antherae 0.5 mm. longae, gynophorum ovario brevius, ovarium 4-loculare, loculi 1-ovulati, stigma carnosum orbiculare. Species antheris minutis sat insignis.

COSTA RICA: In silvis La Palma, alt. 1459 m., Novembri, *A. Tonduz* 12592.

¹ In connection with a systematic study of the flora of Panama, begun under the auspices of the Smithsonian Institution several years ago, there were sent by the United States National Museum to Mr. Casimir de Candolle, for identification, a series of specimens of the family Meliaceae from Central America and Panama. The accompanying paper is a brief report upon this material. Mr. de Candolle's study has resulted in the extension of our knowledge of the group and in the recognition of 12 species and varieties as new, 7 of these being from Panama. The new forms are described in this paper.—FREDERICK V. COVILLE.

2. *GUAREA TUERCKHEIMII* C. DC. Bot. Gaz. 33: 250. 1902, emend.

In diagnosi adde: Capsula globosa glabra in sicco fuscescens, 2 cm. diam.

GUATEMALA: (C. DC. l. c.). Near the Finca Sepacuité, Alta Verapaz, *O. F. Cook & R. F. Griggs* 649.

3. *GUAREA COOK-GRIGGSII* C. DC. n. sp.

Ramulis glabris; foliis longe petiolatis glabris, 3-?-jugis, foliolis oppositis breviter petiolulatis magnis elliptico-lanceolatis basi aequilatera subacutis apice breviter et obtusiuscule acuminatis; paniculis quam folia brevioribus, brevissime pedunculatis glabris fere a basi bifidis, ramis spicatim cymuligeris altero longiore folii dimidium superante, cymulis 1-floris glabris, floribus brevissime pedicellatis parvis; calice acute 4-dentato juniore extus pilosulo; petalis 4 glabris oblongis apice obtusis, tubo stamineo glabro cylindraco margine minute crenulato cum petalis arcte agglutinato, antheris 8 oblongis; ovario glabro gynophorum glabrum superante oblongo-ovato 4-costulato, stilo glabro.

Arbor procera, ramuli floriferi circiter 5 mm. crassi pallidi lenticellis inconspicuis conspersi. Folia alterna 25-? cm. longa. Foliola in sicco firma membranacea minutissime pellucido-punctulata usque ad 21.5 cm. longa et fere 6 cm. lata, nervi secundarii leviter arcuati utrinque circiter 12. Petioli 3 mm. longi, rhachis petiolusque 10 cm. longus supra leviter sulcati. Paniculae ramus maximus 16 cm. longus, pedicelli fere 1 mm. longi, petala in alabastro subadulto oblonga 3.5 mm. longa et usque ad 1 mm. lata, in sicco rubescentia, in aestivatione valvata, antherae ellipticae vix 0.75 mm. longae, ovarium 4-loculare, loculi 1-ovulati.

GUATEMALA: Near the Finca Sepacuité, Alta Verapaz, *O. F. Cook & R. F. Griggs* 408.

4. *GUAREA PALMERI* C. DC. Bot. Gaz. 19: 39. 1894

GUATEMALA: Prope Patulul, Febr., fructifera, *Kellerman* 5698.

EL SALVADOR: *Renson* 97. Viciniis Izalco, Depart. Sonsonate, alt. 400-600 m., *H. Pittier* 1931.

DISTRIBUTIO: Mexico.

5. *GUAREA TERNIFOLIOLA* C. DC. n. sp.

Foliis sat longe petiolatis, 1-3 jugis; foliolis oppositis breviter petiolulatis oblongo-elliptico-lanceolatis basi aequilatera acutis apice obtusiuscule et sat longe acuminatis, supra glabris subtus ad nervum

centralem petiolulisque rhachique et petiolo hirtellis; paniculis breviter pedunculatis simplicibus, florentibus quam folia multo brevioribus, hirtellis, spicatum cymuligeris, cymulis 1-3-floris, floribus pedicellatis pedicellis glabris; calice cyathiformi brevi remote 4-denticulato extus puberulo intus glabro; petalis 4 glabris ovato-oblongis basi truncatis apice acutis; tubo stamineo glabro ovato-cylindrico integro paullo sub fauce leviter contracto, antheris 8 parvis ellipticis paullo supra basin dorsi affixis; gynophoro glabro; ovario conoideo glabro gynophorum fere aequante 4-loculari, loculis 1-ovulatis, stilo glabro tereti, stigmate brevissime cylindrico.

Rami paniculiferi primum hirtelli dein glabri et albicantes usque ad 3 mm. crassi. Folia usque ad gemmulam circiter 10 cm. longa. Foliola in sicco tenuiter membranacea usque ad 14.5 cm. longa et 3.8 cm. lata, nervi secundarii subadscendentes leviter arcuati utrinque 6-7. Petioluli usque ad 4 mm., petioli usque ad 4 cm., pedicelli 1 mm. longi. Petala 9 mm. longa usque ad 2.5 mm. lata. Tubus stamineus 6 mm. longus, antherae paullo sub 1 mm. longae.

PANAMA: Remedios and vicinity, eastern Chiriquí, alt. 0-100 m., *H. Pittier* 5466.

6. *GUAREA PARVA* C. DC. n. sp.

Foliis sat longe petiolatis glabris 4-jugis; foliolis oppositis sat longe petiolulatis obovato-lanceolatis basi aequilatera acutis apice breviter et obtuse acuminatis; paniculis axillaribus brevissime pedunculatis spiciformibus minute puberulis folia aequantibus, rhachi spicatum cymuligera, cymulis paucifloris, floribus breviter pedicellatis; calice cupulari extus puberulo intus glabro adulto irregulariter 4-fisso; petalis 4 oblongis apice subacutis extus adpresse puberulis intus minutissime velutinis, tubo stamineo cylindrico integro glabro. antheris 8 ellipticis paullo supra basin affixis; gynophoro glabro ovario inferne glabro superne hirsuto 4-loculari loculis 1-ovulatis, stilo inferne haud dense hirsuto, tereti, stigmate orbiculari carnoso.

Parva arbor. Ramuli glabri in sicco fusciscentes, floriferi 4 mm. crassi. Folia alterna, 18 cm. longa. Foliola in sicco rigido-membranacea sinuose et haud dense pellucido-punctata, supera 10 cm. longa et 4 cm. lata infera gradatim minora, nervi secundarii subadscendentes fere recti utrinque circiter 10. Petioluli 7 mm. longi, rhachis petiolusque fere 6 cm. longus teretes. Paniculae cum foliis hornotinae florentis 18 cm. longae, pedunculus 1 cm. longus, pedicelli 0.55 mm. longi, calix 2.5 mm. longus in sicco rubescens, petala 9 mm. longa, 2.5 mm. lata in sicco rubescentia, tubus stamineus 6.5 mm. longus, antherae 1 mm. longae.

PANAMA: Forest along Río Indio de Gatún, Canal Zone, near sea level, small tree, fls. white, *H. Pittier* 2810.

7. *GUAREA TRICHILIOIDES* L.

PANAMA: Marraganti, *R. S. Williams* 633.

DISTRIBUTIO: India occidentalis, America meridionalis.

8. *GUAREA TONDUZII* C. DC. n. sp.

Ramulis dense et fulvescente hirsutis; foliis modice petiolatis 4-5-jugis, foliolis oppositis modice petiolulatis oblongo-ellipticis basi aequilatera acutis apice obtuse acuminatis, utrinque ad nervos parce et ad paginam dense fulvescente hirsutis, petiolulis rhachique et petiolo dense fulvescente hirsutis; paniculis breviter pedunculatis fructiferis quam folia pluries brevioribus dense et fulvescente hirsutis, inferne ramulosis superne spicatum cymuligeris; calice obtuse 4-dentato extus capsulaque dense et fulvescente hirsutis; capsula subtetragono-globosa inferne breviter attenuata 4-loculari loculis monospermis.

Arbor 4-5 m. alta, corona rotundata, truncus 12-15 cm. diam. Folia alterna circiter 16 cm. longa. Foliola in sicco rigida, supera usque ad 18 cm. longa et 6 cm. lata, infima cito decidua et haud visa, nervi secundarii utrinque 10-12 leviter arcuati. Petioluli fere usque ad 7 mm. longi, rhachis petiolusque usque ad 3 cm. longus teretes. Panicula fructifera usque ad 8 cm. longa, capsula fere matura 2 cm. diam., cotyledones superpositi.

COSTA RICA: Collines de Tremedal près San Ramón, alt. 1200-1300 m., *A. Tonduz* 17677.

9. *GUAREA BULLATA* Radlk. Bull. Herb. Boiss. ser 2. 5: 192. 1905

COSTA RICA: (Radlk. l. c.) In silvis Río Naranjo, alt. 200-250 m., *A. Tonduz* 7654.

10. *GUAREA WILLIAMSII* C. DC. n. sp.

Foliis modice petiolatis 2-?-jugis glabris; foliolis oppositis breviter petiolulatis ellipticis basi aequilatera acutis apice breviter et obtusiuscule attenuatis; paniculis axillaribus, fructiferis quam folia brevioribus glabris; capsula pyriformi basi breviter attenuata in sicco atrorubescens et lenticellis pallidis conspersa 4-loculari.

Rami paniculiferi glabri 5 mm. crassi in sicco pallide fuscescentes. Folia alterna 11-? cm. longa in specimine incompleta. Foliola in sicco subcoriacea, supera usque ad 13.5 cm. longa et 7 cm. lata, infera

minora conformia. Paniculae fructiferae 7 cm. longae, pedunculus 15 mm. longus 4 mm. crassus. Capsulae circiter 3.5 cm. longae et superne 2.5 cm. latae pars infera attenuata 3 mm. longa.

PANAMA: Boca de Cupe, *R. S. Williams* 683.

11. **GUAREA LONGIPETIOLA C. DC. n. sp.**

Foliis longe petiolatis 4-jugis, foliolis oppositis magnis, sat longe petiolulatis, obovato-lanceolatis basi aequilatera acutis apice obtusiuscule et sat longe acuminatis, supra glabris subtus minute puberulis; paniculis axillaribus, fructiferis quam folia brevioribus breviter pedunculatis glabris pyramidato-ramosis; capsula pyriformi 4-loculari glabra superne lenticellis irregulariter torulosa vel laevi inferne sat longe attenuata, loculis monospermis.

Rami paniculiferi 1.5 cm. crassi glabri in sicco pallide virescentes vel albescentes. Folia alterna usque ad gemmulam 35 cm. longa. Foliola in sicco membranacea minute pellucido-punctulata, supera usque ad 25 cm. longa et 8 cm. lata infera paullo minora, nervi secundarii subadscendentes recti utrinque circiter 12, petioluli 10 mm. longi, rhachis petiolusque usque ad 17 cm. longus teretes. Paniculae pedunculus 2 cm. longus, 7 mm. crassus. Capsula fere matura 5 cm. longa superne 3 cm. crassa, ejus pars infera attenuata usque ad 10 mm. longa.

PANAMA: Boca de Pauarandó on Sambú River, southern Darién, alt. 20 m., *H. Pittier* 5580. Around Garachiné, in forest near sea level, *Pittier* 5697. Vicinity of San Felix, eastern Chiriquí, alt. 0-120 m., *Pittier* 5439.

12. **GUAREA CULEBRANA C. DC. n. sp.**

Foliis modice petiolatis glabris, 15-jugis, foliolis oppositis brevissime petiolulatis magnis obovato-ellipticis basi aequilatera acutis apice breviter et obtuse attenuatis; panicula simplici spicatum cymuligera glabra quam folium pluries brevior; fructu immaturo pyriformi adpresse puberulo 5-loculari, loculis 2-ovulatis ovulis collateralibus.

Arbor. Folia usque ad gemmulam 34 cm. longa. Foliola in sicco rigido-membranacea minutissime pellucido-punctata, usque ad 26 cm. longa et 9.5 cm. lata, nervi secundarii subadscendentes leviter arcuati utrinque circiter 14. Foliola infera utrinque 10, in specimine deficientia. Petioluli fere 3 mm. longi. Rhachis in sicco subteres supra leviter sulcata. Petiolus teres 5 cm. longus.

PANAMA: Along the Río Culebra, above Santa Isabel, Province of Colón, near sea level, *H. Pittier* 4160.

13. **GUAREA PITTIERI C. DC. n. sp.**

Ramulis junioribus velutine hirtellis dein glabris; foliis longe petiolatis 3-4-jugis, foliolis oppositis modice petiolulatis ellipticis basi ima acutis apice modice obtuse vel subacute acuminatis supra glabris subtus rhachique et petiolo velutine puberulis; panicula pyramidatim ramosa velutine puberula folium fere aequante; calice obtuse aut subacute 5-dentato extus dense et adpresse hirtello; petalis oblongis superne attenuato-acutis subtus dense et adpresse hirsutis; tubo stamineo subovato-cylindrico margine integro extus lineatim et adpresse hirsuto, antheris ellipticis; ovario oblongo dense et adpresse hirsuto gynophorum glabrum multo superante 6-loculari, loculis 2-ovulatis ovulis superpositis, stilo inferne adpresse hirsuto, stigmate orbiculari.

Ramuli elenticellosi pallide et rubelle fuscescentes. Folia alterna fere 23 cm. longa. Foliola in sicco firme membranacea pellucido-punctulata et parce pellucido-lineolata, usque ad 14 cm. longa et fere 7 cm. lata, nervi secundarii subrecti utrinque 7-8. Petioluli usque ad 1 cm. longi, petiolus 11 cm. longus. Paniculae ramuli inferi circiter 4 cm. longi, rhachis 5 mm. crassa, cymulae 1-florae, pedicelli 2 mm. longi, calix cum dentibus 5 mm. longus, petala 10 mm. longa et inferne 2.5 mm. lata, in sicco subcoriacea et subtus pallide virescentia, tubus stamineus fere 9 mm. longus, antherae fere 1.25 mm. longae dorso supra basin sessiles.

COSTA RICA: Tuis, prope Turrialba, alt. 620 m., Junio, florens, *H. Pittier* 11245.

TRICHILIA L.

SECTIO EUTRICHILIA C. DC.

14. **TRICHILIA CHIRIQUINA C. DC. n. sp.**

Foliis modice petiolatis impari-pinnatis 3-jugis; foliolis lateralibus oppositis brevissime petiolulatis superis obovato-lanceolatis basi aequilatera acutis apice breviter et obtuse acuminatis emarginulatisque infimis quam superi multo minoribus ellipticis omnibus adultis supra ad nervum centralem subtus ubique et sat dense rhachique hirsutis; paniculis axillaribus terminalibusque folia fere aequantibus axillaribus brevissime et remote ramulosis terminalibus pyramidato-ramosis, ramis rhachique dense hirsutis, ramis spicatim cymuligeris cymulis sessilibus umbelluliformibus; floribus pedicellatis, calice profunde 5-dentato extus dense hirtello intus glabro dentibus ovato-acutis; petalis 5 ovato-acutis extus puberulis intus minute velutinis; tubo stamineo ultra medium laciniato inferne extus glabro intus

villosus, laciniis 10 lineari-oblongis utrinque villosis in apice truncato antheriferis, antheris sessilibus ovatis apice mucronatis pilosulis; disco carnoso hirsuto cum tubo stamineo brevissime stipitato; ovario 3-loculari stiloque hirsutis.

Ramuli hirtelli, paniculiferi 5 mm. crassi in sicco fuscescentes elenticellosi. Folia alterna circiter usque ad 18 cm. longa. Foliola in sicco membranacea epunctulata, supera fere usque ad 11.5 cm. longa et 4.5 cm. lata, infima 2.3 cm. longa et 1.7 cm. lata, nervi secundarii subadscendentes recti in foliolis superis utrinque circiter 12; petioluli laterales 2 mm. terminales 10 mm. longi. Paniculae terminalis rami usque ad 5 cm. longi, pedicelli 1.55 mm. longi. Flores in vivo albi, calix cum dentibus 1.5 mm. longus, petala in aestivatione quincuncialia fere 3.5 mm. longa, 1.5 mm. lata.

PANAMA: Vicinity of David, alt. 30-80 m., *H. Pittier* 2838.

15. **TRICHILIA ALBIFLORA** C. DC. n. sp.

Foliis longe petiolatis 5-8-jugis; foliolis breviter petiolulatis elliptico-lanceolatis terminali basi aequilatera acuto lateralibus oppositis basi inaequilatera acutis omnibus apice acute et sat longe acuminatis utrinque hirsutis, rhachi fere glabra; paniculis adultis folia fere aequantibus longe pedunculatis pyramidato-ramosis sat dense hirtellis, ramis superne ramulosis, cymulis bifloris; floribus breviter pedicellatis, pedicello hirtello; calice extus hirtello intus glabro profunde 5-dentato dentibus ovatis apice subacutis margine ciliolatis; petalis 5 elliptico-oblongis apice subacutis extus glabris intus minute velutinis; filamentis usque ad medium in tubum utrinque glabrum ovato-cylindricum connatis superne lineari-oblongis apice truncatis utrinque et praesertim intus pilosis, antheris in apice filamentorum sessilibus ovato-oblongis; ovario sessili dense et sat longe hirsuto 3-loculari, loculis 1-ovulatis; stilo glabro tereti ovarium aequante, stigmatate breviter cylindrico.

Rami paniculiferi glabri in sicco atrorubescens lenticellis pallidioribus ellipticis conspersi circiter usque ad 5 mm. crassi. Folia alterna usque ad 35 cm. longa. Foliola in sicco membranacea minute pellucido-punctulata, terminalia fere 5.5 cm. longa et 1.9 cm. lata, lateralialia supera usque ad 8 cm. longa et 2.6 cm. lata, infera gradatim minora, nervi secundarii subadscendentes subrecti in foliolis superis utrinque 12. Petioluli usque ad 3 mm. longi. Rhachis petiolusque usque ad 7.5 cm. longus supra complanati. Paniculae adultae pedunculus usque ad 14 cm. longus glaber, rami inferi circiter 6.5 cm. longi. Calix membranaceus cum dentibus 0.55 mm. longus. Petala

in aestivatione valvata membranacea in vivo alba 5 mm. longa usque ad 2 mm. lata. Tubus stamineus usque ad lacinias 1.5 mm. longus.

COSTA RICA: Ojos de Agua, alt. 900 m., Provincia Alajuela, *H. Pittier* 3677.

16. *TRICHILIA BIOLLEYI* C. DC. Bull. Herb. Boiss. ser 2. 5: 423. 1905

COSTA RICA: (C. DC. l. c.) Bords d'un ravin à Nuestro Amo, Llanos de Turucares, alt. 750 m., petit arbre, *H. Pittier* 16395.

17. *TRICHILIA CUNEATA* Radlk. Sitzungsab. Math.-Phys. Akad. München 9: 642. 1879

GUATEMALA: (Radlk. l. c.)

EL SALVADOR: Prope Juayua, Depart. Sonsonate, alt. 800 m., arbor mediocris, *H. Pittier* 1991.

SECTIO MOSCHOXYLUM C. DC.

18. *TRICHILIA HAVANENSIS* Jacq. var. *PILIPETALA* C. DC. n. var.

Ramulis glabris foliis 4-5-jugis, floribus quam in species longius pedicellatis, petalis supra pilis longis munitis.—Vern. Barrehorno.

COSTA RICA: *H. Pittier* 67.

PANAMA: Forests around El Boquete, alt. 1000-1300 m., *Pittier* 3144.

DISTRIBUTIO: India occidentalis, Mexico.

CEDRELA L.

19. *CEDRELA MEXICANA* Roem. Fam. Nat. Syn. 1: 137. 1846

PANAMA: Agua Dulce, Province of Coclé, in savannas, near sea level, *H. Pittier* 4985.

DISTRIBUTIO: India occidentalis, Mexico, Brasilia.

20. *CEDRELA FISSILIS* Vell. Fl. Flum. 2: 75. 1825

PANAMA: Dry wooded hills around Alhajuela, Province of Panama, alt. 30-100 m., *H. Pittier* 3729.

DISTRIBUTIO: America meridionalis.

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DESCRIPTIONS OF TWO NEW BIRDS FROM HAITI

BY
CHARLES W. RICHMOND



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DESCRIPTIONS OF TWO NEW BIRDS FROM HAITI

By CHARLES W. RICHMOND

In a collection recently made by Dr. W. L. Abbott in the northwestern peninsula of Haiti, including Tortuga (or Tortue) Island, there appear to be two new subspecies, descriptions of which are given below. The birds collected on Tortuga represent twenty-three species (another was seen but not obtained), which, with the exception of a vireo, prove to be common Haitian forms.

The most interesting bird in the collection is a *Nyctibius*, a genus not heretofore recorded from the island. Through the friendly cooperation of the Museum of Comparative Zoölogy, it has been possible to compare this specimen with five good examples from Jamaica, for the purpose of establishing its subspecific distinctness.

NYCTIBIUS GRISEUS ABBOTTI, new subspecies

Type specimen.—Adult male, Cat. No. 250374, U. S. Nat. Mus.; Port de Pimente, northwestern Haiti, March 9, 1917, Dr. W. L. Abbott.

Characters.—Similar to *Nyctibius griseus jamaicensis*,¹ but differs in having the black markings on the pileum much reduced in size and extent (not predominating, as in *jamaicensis*), and feathers without any admixture of pale brownish buffy; general aspect of crown brownish gray and white, with black shaft marks, usually becoming broader toward the tips of the feathers, the black markings most pronounced on feathers over the eyes; hind neck and mantle grayer, less brownish; dark bars on rectrices less regular and more broken with gray mottlings and wavy lines; under tail-coverts with narrower and less prominent dark shaft markings; throat more ashy, less whitish, without any traces of cinnamon buff; black submalar streak less prominent; blackish post-ocular stripe barely indicated, not prominent as in *jamaicensis*, the auricular region being mostly gray, with very narrow black shaft lines, the edges of some feathers tinged

¹ Comparison is made with Ridgway's description (Bull. U. S. Nat. Mus., No. 50, Pt. 6, 1914, p. 589) and with six skins of the Jamaican bird.

with buff; feathers anterior to and beneath eye grayish (with black shafts), not prominently marked with black. "Iris brownish yellow."

Measurements of the type.—Length (in the flesh), 448; wing, 297; tail, 218; tarsus, 12; culmen, 25 mm.

Remarks.—Only one specimen was obtained, but Dr. Abbott saw a mounted bird in a store at the Santo Domingo end of the island. The individual collected was "caught alive while sleeping." An analysis of its stomach contents, furnished by Mr. A. Wetmore, shows 83 per cent of moth remains, and 17 per cent other insects and locustid eggs.

VIREO CRASSIROSTRIS TORTUGÆ, new subspecies

Type specimen.—Adult male, Cat. No. 250495, U. S. Nat. Mus.; Tortuga Island, Haiti, Jan. 31, 1917, Dr. W. L. Abbott.

Characters.—Similar to *Vireo crassirostris crassirostris*, as described by Ridgway,¹ but differs in having the under surface (except lower abdomen and crissum) tinged with maize yellow,² becoming naples yellow or straw yellow on chest, sides and flanks; auricular region and sides of neck pale isabella color; under wing-coverts white, with a buffy tinge, more or less mingled with dusky on the under primary coverts. In *Vireo c. crassirostris* the under surface is tinged with sulphur yellow, the auricular region and sides of neck are light yellowish olive, and the under wing-coverts have a tinge of primrose yellow. The new form is slightly darker on the mantle, and the size is a little inferior to that of the Bahaman bird.

Measurements of the type (adult male).—Length (in the flesh), 134; wing, 60; tail, 51.5; tarsus, 20.5; culmen, 13 mm.

Average measurements of eight adult males.—Length (in the flesh), 131.5; wing, 60.7; tail, 49.9; tarsus, 20.4; culmen, 12.7 mm.

Average measurements of three adult females.—Length (in the flesh), 131.3; wing, 57.1; tail, 47.1; tarsus, 21; culmen, 12.5 mm.

Average measurements of Vireo c. crassirostris.³—Males: wing, 63.3; tail, 50.7; tarsus, 21.6; culmen, 12.6 mm. Females: wing, 61.2; tail, 48.8; tarsus, 21.1; culmen, 12.3 mm.

Geographical distribution.—Tortuga Island, off the northwest coast of Haiti.

Remarks.—The occurrence of a representative of the Bahaman *Vireo crassirostris* on Tortuga Island (only 50 miles from Great

¹ Bull. U. S. Nat. Mus., No. 50, Pt. 3, 1904, p. 189.

² Ridgway, Color Standards, pl. 4.

³ As given by Ridgway, Bull. U. S. Nat. Mus., No. 50, Pt. 3, 1904, p. 189.

Inagua) is of interest, though of no special significance, since subspecies are known from the Cayman Islands and even from Old Providence, the last more than 700 miles distant from the nearest point in the Bahamas.

Dr. Abbott found this bird "in pairs and the commonest species in dense bush," and specimens were collected from Jan. 30 to Feb. 8. The iris is noted as "gray" or "grayish white"; the feet and bill "leaden."

SMITHSONIAN MISCELLANEOUS COLLECTIONS

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WATER-VAPOR TRANSPARENCY TO LOW-TEMPERATURE RADIATION

BY
F. E. FOWLE



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WATER-VAPOR TRANSPARENCY TO LOW-TEMPERATURE RADIATION

BY F. E. FOWLE

The main purpose of this research was to determine the transparency of water vapor, under atmospheric conditions, to radiation such as the warm earth sends toward space. Upon the absorptive property of water vapor rests in part the virtue of the atmosphere as a conservator of the heat which the earth receives from the sun. Radiation from the sun reaches the earth's surface diminished by a certain portion scattered toward space and certain other portions absorbed in the gases and vapors of the atmosphere. The return of the energy of this radiation back to space is an indirect process. The warmed earth is cooled partly by convection currents playing over its surface and partly by direct and indirect radiation through the constituents of its atmosphere. Of these the principal hindrances to free radiation are aqueous vapor and carbonic acid gas.

The radiation from the sun, at an apparent temperature of 6,000 to 7,000° K.,¹ passes through the atmosphere with comparatively little true absorption. Nearly all of the radiation of a body of this temperature lies at wave-lengths shorter than $2\ \mu$. At sea-level on a clear day when the sun is in the zenith only about 6 to 8 per cent is absorbed from the direct solâr beam within the great infra-red bands $\rho\sigma\tau$, ψ , ϕ and Ω in its passage to the surface of the earth.² The amount scattered from the direct solar beam by the dust and molecules of the air amounts to considerably more but after subsequent reflections in considerable part reaches the earth.³

The radiation from a body of the temperature of the earth, which may be taken as about 287° K., is of wave-lengths nearly all greater than $2\ \mu$ and is hindered by quite a different series of absorption bands in its passage outward through the air. These absorption losses are caused principally by the water vapor and carbonic acid gas present in the atmosphere. This present research will treat

¹ In what follows the symbol K. denotes absolute temperature in centigrade degrees.

² *Astrophysical Journal*, 42, p. 406, 1915.

³ See *Annals of the Astrophysical Observatory of the Smithsonian Institution*, Vol. 3.

chiefly of the transparency of water vapor at wave-lengths greater than $2\ \mu$.

Figure 1 shows graphically the relative positions and intensities in the normal spectrum of the energy radiating from two bodies of

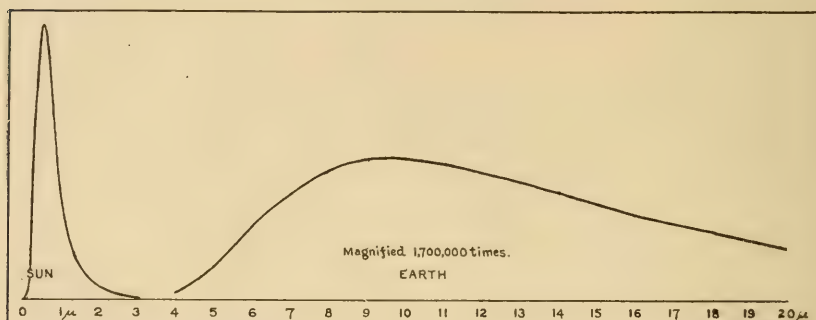


FIG. 1.—Computed black-body energy curves for two bodies of equal size, one at $6,000^{\circ}\text{ K.}$ (sun), the other at 287° K. (earth).

equal size, one at the temperature of the sun, the other at that of the earth.

HISTORY OF THE PRESENT RESEARCH

At first thought it might seem easy to obtain the main object of this research by observing in the laboratory the total radiation of a body at the temperature of the earth, after that radiation had passed through various amounts of atmospheric aqueous vapor. However, the complication then introduced by the radiation from the vapor itself renders the analysis and interpretation of the results difficult if not ambiguous. So recourse is necessary to the use of the radiation from a source at a high enough temperature to make negligible the radiation from the vapor itself and its low temperature surroundings. But then a new trouble arises for the total radiations of bodies at different temperatures are of different qualities and differently affected by the absorption powers of the aqueous vapor. In order to apply the results to the case of the earth's radiation, it is therefore necessary to know the absorptions from wave-length to wave-length and the comparative distribution of energy in the spectrum of the laboratory source of radiation and of the earth. This requires the introduction of the spectroscope with its attending difficulties.

Preparations for observing quantitatively the transmissibility of radiation by aqueous vapor in the spectrum region of the earth's emission were begun in 1908. The radiation which it was proposed

to observe in the region between $2\ \mu$ and $20\ \mu$ is wholly invisible and very feeble even in the emission from the hottest terrestrial sources so that extremely sensitive measuring apparatus was necessary. Few substances are transparent to it. Glass as a rule is non-transparent for wave-lengths greater than $2\ \mu$, quartz for those greater than $3\ \mu$, and fluorite for those greater than $10\ \mu$. A plate of rock salt 1 cm. thick absorbs 50 per cent at $17\ \mu$ and one of silvite 50 per cent at about $21\ \mu$. As silvite was not available it was necessary to use rock salt of which the Observatory, through the courtesy of the Russian Government, possesses a number of large and beautiful prisms.

Preparations had to be made for observing a great range of intensities. The radiation from a Nernst lamp, such as was used in this research as a source of energy at a temperature of about $2,200^\circ\text{K.}$, is at $20\ \mu$ only $1/100,000$ as intense as it is at $2\ \mu$. The difficulties inherent in finding proper means for observing accurately over such a range of intensities will be discussed when the means are described.

No mirror perfectly reflects an incident beam in one direction. An appreciable portion of the beam is scattered in all directions as may be easily noted by looking from any direction at a silvered mirror upon which a beam of sunlight falls. This scattered light becomes more and more troublesome as that part of the spectrum is approached where the intensity is only $1/10,000$ that in the brightest part. Field light, as it is usually called, finally amounts to the whole of the observed energy. Means had to be provided either for eliminating or measuring it.

In order that the air, the transparency of which was to be measured at normal atmospheric conditions as to temperature and pressure, should contain sufficient water vapor, it was necessary to make most of the observations during the hotter summer months. Air of 50 per cent relative humidity at a summer temperature of 40°C. contains 12 times as much water vapor as of the same relative humidity and a winter temperature of 0°C. Even then, with the length of path possible in these laboratory experiments, the air column contained only as much vapor as may be found in the atmosphere during the winter months along the zenith path of the sun's radiation to the earth. On a summer day there may be 10 times as much vapor as this in the sun's path.

In 1908 preliminary experiments were made at intervals between the regular work of the Observatory. During 1909 and 1911, in the

lack of sufficient sensitiveness of the apparatus for measuring the feeble radiation of the longer wave-lengths, certain measures were made connecting the amounts of absorption in the bands of the upper infra-red, $0.7\ \mu$ to $2.0\ \mu$, with the quantity of water vapor producing them.¹ These bands are those affecting the incoming radiation from the sun.

In the early part of the summer of 1913 attempts were made to use a vacuum bolometer which Dr. Abbot had meanwhile prepared. The air-pump, then in the possession of the Observatory, was not suitable and the summer became so far spent that the experiments were finally carried on without a vacuum. When the results were reduced the next winter a serious discrepancy was found, the cause of which was so obscure, that it escaped detection for some time. It necessitated the repetition of the experiments in the summer of 1914. This source of error lay in the circumstance that in the form of lamp then used for the radiation source, the bolometer was exposed to a source of somewhat different effective temperature when the radiation passed through the water-vapor tube than when it passed through the spectroscope alone. The comparison of the observed energies in the two cases was to serve as a measure of the absorptions due to the water vapor and thus the change in quality of the rays just explained caused error. This error was avoided by the use of proper diaphragms and the construction of a more suitable and far more effective form of lamp. Some doubt as to the matter of field light required further observations during the summer of 1916. Because of complications resulting from the absorption of the radiation by carbonic-acid gas, further observations were made during some very cold days of the winter of 1916-17. On such days the losses due to

¹The results of these observations were published in a series of articles in the *Astrophysical Journal* discussing the transmission of radiation through moist and dry air and water vapor between the wave-lengths 0.35 and $2.0\ \mu$. The first (l. c. 35, p. 149, 1912) gave the laboratory calibration, with known amounts of water vapor, of the intensity of energy in the bottom of certain absorption bands, the depths of which could be accurately measured bolometrically. The second (37, p. 359, 1913) gave applications of the first paper to the spectroscopic determination of the water vapor above Mount Wilson and a comparison of these values with determinations by Hann's formula. The third (38, p. 392, 1913) treated of the non-selective scattering of dry air and water vapor for the spectrum region 0.35 and $2.0\ \mu$. The fourth (40, p. 435, 1914) was concerned with the application of the dry-air transmission coefficients to the determination of Avogadro's constant, the number of molecules in a gram-molecule of any gas. The fifth (42, p. 394, 1915) gave the corresponding selective absorptions in the spectrum region 0.35 to $2.00\ \mu$.

aqueous vapor would be at a minimum, whereas the carbonic acid gas would be practically as effective an absorber as in the summer time. Finally, because of both the unexpectedly small absorption of radiation at the longer observed wave-lengths and the too-small quantity of aqueous vapor possible in the laboratory experiments, observations were made in April, 1917, of the atmospheric absorption of the radiation from the sun itself.

The necessity of the right-working of so many unruly processes, the galvanometer, the bolometer, the source of radiation, a transformer working far beyond its capacity in furnishing current for the lamp, the need of sunny weather, not too damp for the use of rock salt nor too windy for the galvanometer or bolometer, and without too many of the ever-prevalent summer cumuli—all these requirements tended to make the securing of good observations a tedious process. Often, too, all the difficulties had to be attended to single-handed.

Before proceeding the writer wishes to express his gratitude to Dr. C. G. Abbot, the Director of this Observatory, who not only suggested the research but at all stages was ever ready to help with suggestions and criticisms in the many perplexing problems.

WORK OF OTHER INVESTIGATORS

Although less than 1 per cent of the sun's incoming energy lies at a wave-length greater than 2μ , nevertheless the intensity of the sun's heat is so great that measurable energy would be expected at greater wave-lengths unless lost in passage through the constituents of the earth's atmosphere, or possibly in the gaseous envelopes about the sun itself. Langley,¹ in his solar and lunar spectrobolometric researches, found indications of energy between 2.0 and 2.5μ , 2.8 and 4.0μ , and 4.5 and 5.3μ . Beyond the maximum at 4.6μ , Langley states, "lies the longest break of all, stretching from 5.0 to 7.7μ ." Between 8.4 and 9.1μ and at 10.7μ there is practically complete transmission as indicated by observations to an air mass of 3.76 , and the observed decrease in transparency for greater air-masses is probably due to the smoke in the atmosphere.

¹The Solar and Lunar Spectrum, Memoirs National Academy of Sciences, IV, p. 159-170, 1888. Note: The longer wave-lengths given by Langley are in error and have been corrected by means of his recorded deviations and a deviation-wave-length curve computed from the dispersion data for rock salt given in Vol. I of the Annals of this Observatory.

Paschen¹ investigated the transparency of carbon dioxide and water vapor. He used a column of steam 7 cm. long at atmospheric pressure. Between the wave-lengths 1 and 9μ he showed definitely the absorption due to each absorbent. He also gives four curves showing the energy curves to about 9μ of a blackened platinum strip at 450° C. observed through an empty fluorite cell and with the cell containing films of liquid water, 0.01 to 0.02 mm., at least 0.03 mm., and 0.08 mm. thick. The principal liquid water bands of this region lie at 2.9, 4.7, 6.1μ .

Rubens and Nichols² found but a small absorption due to water vapor for the energy from a terrestrial source selectively reflected from fluorite at 24.4μ . Energy of this wave-length could not have been found in the solar spectrum by the earlier observers owing to its absorption in their prisms of rock salt or fluorite. Rubens and Aschkinass³ pursued the experiments using selectively reflected sun-light of the same wave-length, 24.4μ , with purely negative results, no deflections were obtained. They then proceeded to the examination of the transmission of energy from a laboratory source through 40 cm. of steam at atmospheric pressure. The results of Rubens and Aschkinass and of Paschen will be given later in more detail in connection with the results of the present research. Their results were all obtained with steam at 100° C. and 76 cm. pressure whereas the results of the present contribution were obtained at atmospheric conditions both as to temperature and to total and partial pressures.

Rubens later, using the residual radiations selectively reflected from various crystals, found that water vapor has strong absorption between 45 and 120μ , this being especially intense at 50μ , 66μ , and 79μ . Relatively high transparency occurs at 47μ , 54μ , 62μ , 75μ , 91μ , and at 115μ .⁴ In an earlier research with Wartenberg⁵ he found that a column of steam 40 cm. long and at atmospheric pressure transmits radiation as follows: 39.6 per cent at 23μ , 0.7 per cent at 52μ , 19.6 per cent at 110μ , and 49.2 per cent at 314μ . These results are not necessarily at variance with the earlier statement that with selectively reflected sun-light purely negative results were obtained at 24.4μ by Rubens and Aschkinass. For some other

¹ *Annalen der Physik und Chemie*, 51, p. 1, 1894; 52, p. 209, 1894.

² *Idem.*, 60, p. 418, 1897.

³ *Idem.*, 64, p. 548, 1898.

⁴ *Berichte Kgl. Preuss. Akademie der Wissenschaften*, 1913, p. 513.

⁵ *Verh. Deutsche Physikalische Gesellschaft*, 13, p. 797, 1911.

atmospheric absorber than aqueous vapor may have removed the energy of this wave-length from the solar beam.

TEMPERATURE AND PRESSURE EFFECTS

The effect of pressure on the absorption of radiation by gases has been investigated principally by Miss Eva von Bahr.¹ In general the absorption of the same quantity of gas is increased by increasing its pressure. The absorptive power exerted by a gas present in another gas does not depend merely upon its partial pressure but upon the total pressure of the mixed gases as well. For instance, let the absorption of a given quantity of a gas in a tube be measured; if the gas be then allowed to expand, in such a manner that the weight of gas in the path remains the same, the absorption would in general decrease. If a non-absorbing gas be then admitted until the total pressure is restored, the original value of absorption will be regained. This absorbing power of a gas in general increases with increasing pressure somewhat rapidly at first, then more slowly, and the maximum constant power of absorption for a gas is not reached until under pressures ranging from 50 cm. for CS_2 to 400 cm. for CH_4 and CO_2 .

Unfortunately the variation of the transmission with the pressure has been determined for only one of the absorption bands now under consideration. Miss von Bahr gives for the water-vapor band at 2.7μ the following values for the absorption of a constant amount of vapor under the varying pressures:

105 mm.	4.6 per cent.	405 mm.	8.5 per cent.
235 "	7.2 "	570 "	10.6 "
370 "	8.6 "	755 "	12.0 "

The increase in pressure was produced by introducing dry air which exercised practically no absorption at this place in the spectrum. Miss von Bahr states that the "change of its absorption as dependent upon the total pressure is in general (for the same gas) the same in the different bands."²

The present research is carried out on vapor at 76 cm. total pressure whereas part of the vapor in the atmosphere is at a considerably

¹ Annalen der Physik, 29, p. 780, 1909; 33, p. 585, 1910; Verhandlungen der Deutsche Physikalische Gesellschaft, 15, p. 673, 1913.

² Die Änderung der Absorption auf Grund des Gesamtdruckes ist in allgemeinen die Gleiche in verschiedenen Banden.

reduced total pressure. It may give a fair estimate of the error committed in using these laboratory values for the transmission of the atmospheric water-vapor in the path of the sun's or earth's radiation, to use the observations of Miss von Bahr just tabulated. Using the distribution of aqueous vapor at different altitudes as given by Humphreys,¹ a vertical column of air, which would give a transmission of 88 per cent with a total pressure uniform throughout at 76 cm., would give, with a distribution of pressures such as actually exists in the atmosphere, 90 per cent in summer, 89 in winter according to the measures of Miss von Bahr. With the distribution of vapor above Mount Wilson, the transmission comes out 90 per cent for both summer and winter. That is, it would take a slightly greater amount of vapor to produce an absorption noted in the spectrum of a celestial body than would be expected from the laboratory data. If the observations are made at the surface of the earth, the difference would be 1 or 2 per cent and about 3 per cent if made at Mount Wilson.

Of the effect of temperature on the amount of absorption of gases comparatively little is known. Miss von Bahr² considers that its effect is certainly different from that of pressure. She interprets her results to mean that an increase of temperature causes a considerable damping by the absorbing particles whereas an increase in pressure up to a certain limit merely influences things by increasing the number of absorbing particles. A comparison of the results obtained with steam with those obtained under atmospheric conditions as regard to temperature indicates that less absorption would be expected at the lower temperature.

APPARATUS AND METHOD OF OBSERVING

The arrangement of the optical apparatus is shown schematically in figure 2. Radiation from the source N, composed of Nernst lamps, passed 42.5 meters through the tube T, containing the water vapor, to the mirror M_1 , 51 cm. in diameter, thence, collimated, 16 meters to the flat mirror M_2 , 76 cm. in diameter, thence back to M_1 , and then to focus on the slit of the spectroscope at S. Before entering the spectroscope the beam could be returned over the path through the water vapor by means of two flat mirrors, F_1 and F_2 , close beside the slit. The first arrangement gave a path through the water vapor of about 117 meters, to which must be added the

¹ Bulletin of the Mount Weather Observatory, 4, p. 121, 1911.

² Annalen der Physik, 38, p. 206, 1912.

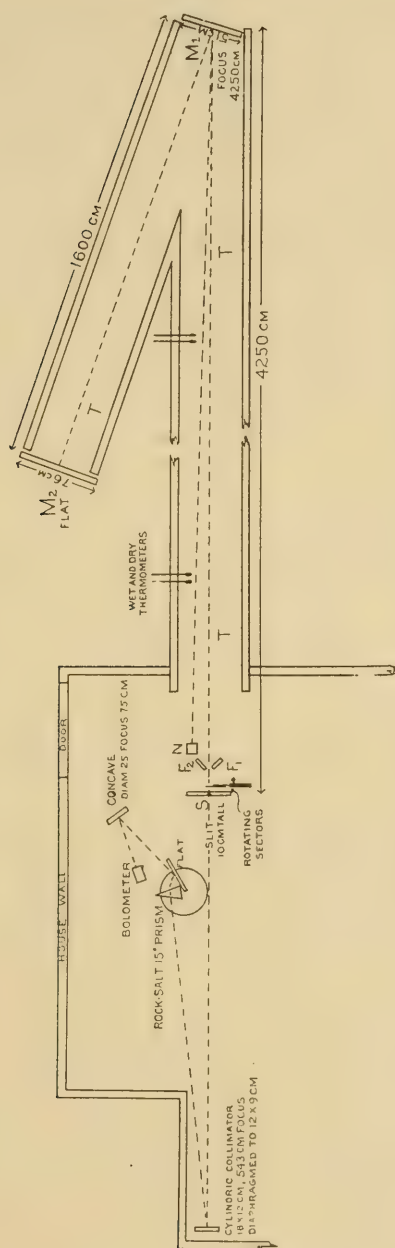


FIG. 2.—Plan of water-vapor tube and spectro-bolometric apparatus.

path through the spectroscope making a total path of 128.5 meters (422 feet). The second arrangement totaled 245.5 meters (806 feet). The source *N* could be turned towards the slit and its radiation passed directly into the spectroscope. Its path through water vapor then amounted to only 11.5 meters (38 feet).

The differences of the observed intensities of the spectrum energy after passing over the various paths served to measure the energy absorbed in the water vapor.

In consequence of the long path of about 43 meters to the collimator *M*₁, but a small part of the energy sent out by the lamp was utilized. A shorter focus collimator would have been no better except with a point source of radiation; for as the source was 10 cm. tall, the extreme divergence of the bundles of parallel rays from the

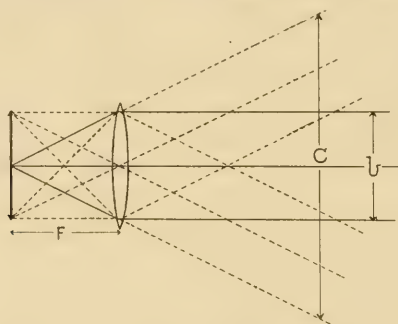


FIG. 3.—*F*, principal focus of lens; *b*, collimated rays from point source; *C*, collimated rays from linear source.

two ends of the source would have overbalanced the gain in incident energy on the collimator from the lamp (see fig. 3). Unfortunately there was a serious vibration of the image of the lamp formed on the slit due to the great magnification of the small tremors of the mirrors. These two causes, the small angular aperture of the mirror and tremor of the image, went far to limit the accuracy obtainable in the observations.

The energy, after entering the slit of the spectroscope, passed to a cylindrical collimator (straight elements vertical) of 543 cm. focus, diaphragmed down to 12 by 9 cm.; thence it passed to a rock-salt prism with Wadsworth minimum-deviation attachment, then to the concave mirror of 75 cm. focus which formed the spectrum on the bolometer. All the mirrors were silvered on glass.

THE WATER VAPOR

The water vapor was contained in a large double-walled galvanized-iron tube, open at its ends. Suitable compartments being provided in the double wall, and numerous holes leading from these

into the inner tube, a 22 horse-power rotary blower served to thoroughly stir the air and aqueous vapor. Alternate compartments were supplied with pressure and exhaust. This stirring was necessary in order to prevent stratification of the air and the consequent blurring and drift of the image of the lamp. It was not desirable to run the blower during an actual spectrum record because of the tremors communicated to the mirrors and to the galvanometer.

The amount of water vapor was determined by wet and dry thermometers at the spectroscope, at the mirror shelters and at several places in the tube. These were read while the air in the tube was stirred by the blower. Check determinations were made several times by Mr. L. B. Aldrich, who absorbed and weighed in tubes of calcium chloride and phosphorus pentoxide the water vapor from known volumes of air taken from the tube. The following table gives the water per cubic meter as measured by the two methods:

By wet and dry thermometers	Absorbed by $\text{CaCl}_2 + \text{P}_2\text{O}_5$
3.25 grams per cu. m.	3.29 grams per cu. m.
3.82 " " " "	3.85 " " " "
7.96 " " " "	8.76 " " " "

The amount of vapor in the tube could be increased by the introduction of a jet of steam into the blower. But when the vapor pressure of the water vapor within the tube differed much from that without an equalization took place so rapidly as to render this procedure useless.

The following table shows a determination of the amount of water vapor in the large tube just preceding, (a), and after, (b), an observation on the transmissibility of radiation through the vapor in the tube.

AUGUST 11, 1914. BAROMETER 76.5 cm.

Dry thermometer....	35°7	37°9	39°7	36°3	36°7	40°7	43°0	42°3
Wet thermometer....	26°9	27°5	27°9	27°0	26°9	28°4	29°0	28°3
g. per m ³	20.4	20.4	20.2	20.4	19.9	20.5	19.3	19.7
Mean g. per m ³	(a) 20.4				(b) 19.9			

$$\text{Amount of vapor in path through tube} = 117 \times 20 \times .0001 \\ = 0.234 \text{ cm. ppt. H}_2\text{O.}^1$$

¹ For brevity the amount of absorbing vapor will be stated as so much precipitable water, "ppt. H₂O," meaning the depth of liquid water, which if evaporated into a column of the same cross section, would produce the absorbing layer of vapor. This should not be construed as meaning that the liquid water produces the same amount of absorption as the corresponding vapor.

SOURCE OF RADIATION

The radiation used in the following experiments was finally furnished by a lamp of 44 Nernst-lamp double-glowers or 88 filaments. It would have been impracticable to use any inclosed radiator because of the absorption in the inclosing material of the very radiations required.

Within a rectangular frame of soapstone (a), figure 4, was mounted the series of filaments (b). To the rear of the filaments the soapstone was cut away so that the radiation observed from between the filaments was that from the walls of the room at nearly the temperature of the rest of the spectroscope and not radiation from the hot material of the frame of the lamp.¹ The glowers were clamped between copper blocks on each side. In the under copper blocks were ruled grooves into which the platinum ends of each glower were carefully placed. Over these ends were laid strips of platinum foil, then the upper blocks were clamped tightly down upon the ends of the glowers. The foil, as well as several horizontal deep saw cuts in the somewhat stiff upper blocks, was necessary to insure sufficient contact on the filaments to hold them in place and to furnish them with electrical current.

The Nernst glowers do not conduct an electrical current at ordinary temperatures. They were heated by a blast lamp until they would conduct. Then when once conducting they would become hotter and hotter, conducting better and better as their temperature rose, until they would have melted if they had not been provided with so-called "ballast" series resistances. These iron-wire ballasts were so chosen that their increase in resistance with the temperature-nearly compensated the decrease in resistance in the filament due to rising temperature. The ballasts were located in a separate box. The lamps were pushed to their utmost output and they frequently burned out. Although rated at nearly an ampere each the whole 44 in the second lamp would stand but a little over 15 amperes on an open-circuit voltage of 110 volts. The black-body curve best fitting their energy curve indicated an effective temperature of about 2,250° K.

¹ This provision was important. In the earlier lamp the filaments were inclosed in a hollow in the soapstone; but the soapstone, although doubtless helping to keep the lamp at a steady temperature, was not near enough to the temperature of the filaments to produce approximately equal radiation intensity as a part of a black-body source and too near this temperature to have its radiation negligible, whence the error earlier mentioned. The room temperature was so near that of the bolometer that its radiation seen through the interstices of the filaments was negligible.

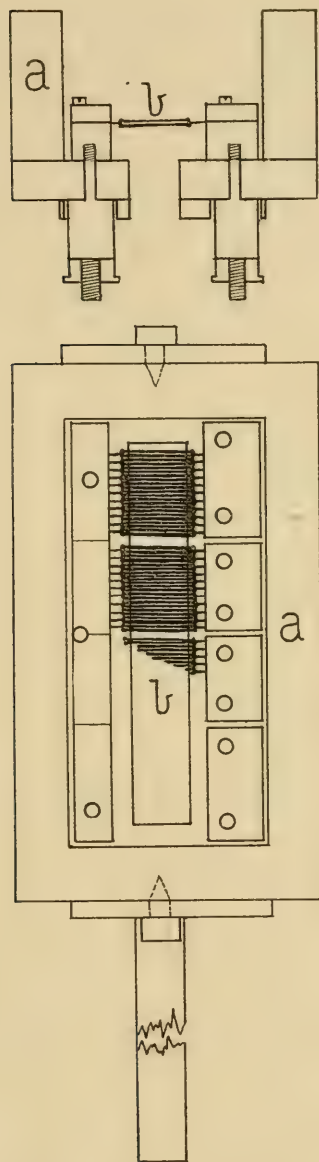


FIG. 4.—Lamp of 88 Nernst filaments. $\frac{1}{2}$ size.

NOTE.—Each pair of filaments was placed so that one filament was slightly to the rear, enabling them to be assembled in closer order.

THE SLIT

The slit was 10 cm. tall with jaws opening bilaterally. Because of the great range of intensity to be observed, from one to a hundred-thousand fold, from one end of the spectrum to the other, some means had to be provided for altering and knowing accurately the amount of alteration in the amount of energy flowing through the slit. It was thought best not to depend upon the readings of the slit micrometer screw for accurately measuring the widths of slits used.

In the earlier part of the research relating to the upper portion of the spectrum, 2μ to 10μ , when the lamp used had its filaments vertical, a lateral change of the slit opening would have been bad because of the irregular lateral changes in the intensity in the lamp. Accordingly a constant slit width was used just wide enough, or less, to be covered by the lamp image, and a series of horizontal grids or diaphragms was used to lessen the intensity of the spectrum. This scheme had the disadvantage of giving a low purity of spectrum corresponding to the great slit width necessary in the least intense part of the spectrum. It had the advantage of allowing the more accurate determination of the energy reducing value of the diaphragm. For the change of deflection when the diaphragm was inserted was not complicated by changes in the purity of the spectrum such as would attend change of slit width. Besides this, owing to having a wide slit, the trouble from diffraction presently to be described did not take place.

For the observations reaching to the greater wave-lengths, a lamp with horizontal filaments was used, the intensity of which was therefore uneven in the vertical direction. The largest slit width for a run was set by closing the slit until the jaws just touched a cylindrical template (4.99 mm., 5.82 mm., or 10.69 mm. in diameter). In the more intense regions of the spectrum the slit was reduced by turning up in succession in front of it two accurately cut slits the widths of which had been measured on a comparator (2.36 mm. and 0.67 mm.). Four rotating sectors could also be used for reducing the energy, which according to their mechanically measured apertures, reduced in the ratios, 0.333, 0.1054, 0.0501 and 0.00512 respectively.

All this provision for making reductions of intensity with accuracy proved somewhat illusory. It has been found here and by others¹ that rotating sectors do not cut down the energy proportionally to their mechanically measured apertures as would be expected. For instance the 0.333 sector cut down the energy by 0.344 as determined

¹ Coblentz, Bulletin Bureau of Standards, 4, p. 455, 1907.

by deflections of the galvanometer before and after the insertion of the sector. It is to be noted that the values of intensity transmitted by rotating sectors which have been observed here in several instances and by Coblentz are always greater than the theoretical value.

Further, not even the vertical slits of fixed widths proved satisfactory and widely differing reduction values were obtained in using them. The cause was obscure until Dr. Abbot suggested that the wave-length of the energy might be sufficiently great to cause large spreading of the beam by diffraction¹ even with the wide slits in use (*e. g.* 2.36 mm.). The fact that this trouble occurred only when the energy passed through the water-vapor tube and an image of the lamp was formed by the mirror M_1 on the slit seems to support the explanation. For in this case the light just filled the diaphragmed collimator of the spectroscope, and diffraction would, as soon as the wave-length was great enough, spread the light beyond both sides of the diaphragm when the narrower slit was up and not when the wider slit was in use. The increasing spread of the light with greater and greater wave-lengths would result in greater and greater reducing ratios for the diaphragm as determined by the deflections for greater and greater wave-lengths. When, however, the energy from the lamp flowed directly through the slit into the spectroscope it so over-filled the collimator that doubtless what was diffracted off from the mirror on one side was diffracted on, so to speak, from the energy already off on the other side. Unfortunately the observations were reduced, because of the press of other work, over a year after they were made, so that there was no opportunity for full investigation of the supposed diffraction phenomena.

THE BOLOMETER AND GALVANOMETER

For the first part of the research extending to 10μ a bolometer strip 0.1 mm. wide by 12 mm. tall was used. Its resistance was about 4 ohms. No plate of any material whatever closed the front of the bolometer case. For the latter part of the work a bolometer strip 0.5 mm. wide by 12 mm. tall was used. The current of 0.04 ampere through the bolometer strip was furnished by two storage cells in parallel. This current was increased to 0.08 and finally to 0.13 ampere for the 1916-17 work. The bolometer strip was placed in an air-tight case, the front being closed with a 1 cm. thick rock-

¹ Annals of the Astrophysical Observatory of the Smithsonian Institution, 1, p. 79, 1900; Lick Observatory Bulletins, 3, 42, 1904.

salt plate fastened on air-tight with white wax. The transmissibility of radiation through this plate will be found in table I under the section relating to the prisms.

The galvanometer is the same as that described on page 32 of Vol. 2 of the Annals of this Observatory. The proportionality of its deflections to the current was tested each year and found to be satisfactory. A time of single swing of about 3 seconds was generally used. The sensitiveness of the apparatus was such that a change of

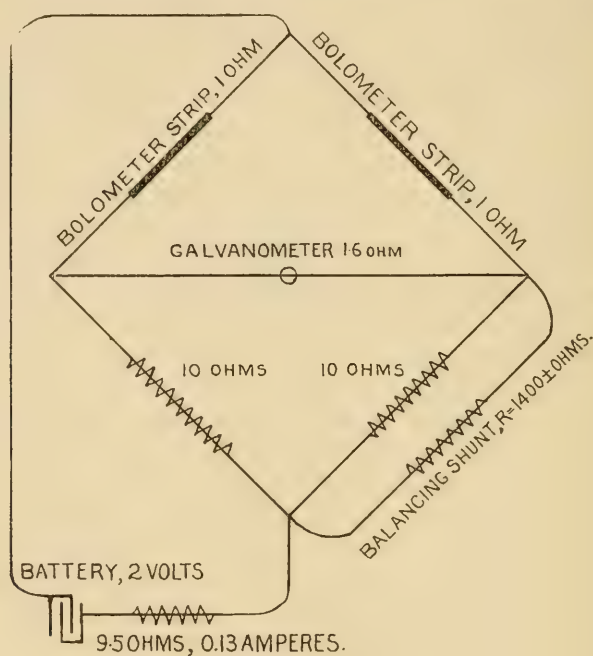


FIG. 5.—Bolometer circuits.

resistance in R (see fig. 5) of one ohm caused a deflection of nearly 3 cm.

The galvanometer deflections were recorded on a photographic plate moved by the same clock which moved the spectrum over the bolometer. The following were the various speeds used for the plate and spectrum:

1908, 1 m. of time	= 4 cm. of plate	= 20' of spectrum
1914, 1 m. of time	= 1 cm. of plate	= 8' of spectrum
1916, 1 m. of time	= 1 cm. of plate	= 4' of spectrum

ROCK-SALT PRISMS

For the work down to about $10\ \mu$ two rock-salt 60° prisms were available, one with faces 18 cm. tall by 15.5 cm., the other 19 by 12.7 cm. The former was cut from an especially clear crystal and was generally used. For the work extending to greater wave-lengths two rock-salt prisms of about 15° were used with faces 13.4 tall and 8.3 wide, 0.4 cm. thick at the refracting edge, 2.7 cm. thick at the base. Further the front of the bolometer case was closed by a rock-salt plate 1 cm. thick. Table I gives in line (1) the coefficient of transmission for rock salt (a , in the formula e^{-ad} where d is the thickness in cm.), (2) the mean transmission for the smaller prism, using the mean thickness, 1.5 cm., (3) the transmission for the rock-salt plate 1 cm. thick, (4) the transmission for the two combined, (5) approximate values for the amount of light reflected from the 4 rock-salt surfaces and (6) the complete transmission factor.

TABLE I.—TRANSMISSIBILITY OF ENERGY THROUGH ROCK-SALT PRISM AND PLATE

Wave-length	5μ	10μ	12μ	13	14μ	15μ	16μ	17μ	18μ	19μ	20μ
a^1.....	....	.005	.007	.0243	.0715	.167	.414	.662	1.29	2.34	5.1
Prism	1.00	.993	.990	.964	.898	.779	.537	.370	.144	.030	.000
Plate	1.00	.995	.993	.976	.931	.846	.661	.516	.275	.096	.000
Prism + plate.	1.00	.988	.983	.941	.836	.659	.355	.191	.040	.003	.006
Reflected.....	.161	.149	.142	.137	.133	.129	.124	.118	.115	.107	.090
Transmitted..	.839	.841	.843	.812	.726	.574	.311	.168	.035	.003	.009

To protect the prisms from hygroscopic fogging of the refracting surfaces, they were covered with a thin film of asphalt varnish. A very dilute solution of asphalt in benzol was made, the freshly polished surfaces were dipped in this and the excess allowed to rapidly flow off. An even, very thin, nearly colorless film could thus be obtained. Its absorption for the long-wave radiation used was found to be inappreciable. Despite these protecting films the prisms fogged and were often repolished before each day's observation, and sometimes twice a day. A tube of phosphorus pentoxide (P_2O_5) kept close to the little-exposed and well-varnished rock-salt plate which closed the bolometer case entirely prevented fogging.

The following table gives the data relative to the dispersion of the various prisms used. The wave-lengths, λ , are given in microns or millionths of a meter, μ . The deviations, $\Delta\theta$, are in minutes of arc

¹ Rubens and Trowbridge, Wiedemanns Annalen, 60, p. 737, 1897.

(') measured from the sharp maximum in the spectrum of the lamp at 1.838μ . The true deviations, θ , equal $39^\circ 33.7' + \Delta\theta$ for the 60° rock-salt prism and $8^\circ 9.9' + \Delta\theta$ for the small rock-salt prism. The plate distances, d , are in cm. measured from the position of the maximum at 1.838μ as zero. $d\theta/d\lambda$, given on an arbitrary scale, is for use in transforming the energy curves from the prismatic to the normal scale. $dd/d\alpha$, is the change in deviation, d , in cm. for a change in the angle of the prism of one degree. The deviations were computed from the indices of refraction given by Paschen.*

TABLE 2.—DISPERSION DATA
60° ROCK-SALT PRISM

λ in μ ,	1	2	3	4	5	6	7	8	9	10
$\Delta\theta$ in '	-27.0	+2.5	15.0	28.0	44.0	62.0	84.0	108.0	135.0	170.0
d in cm. . . .	-5.4	+0.5	3.0	5.5	8.7	12.3	16.7	21.6	27.0	33.9
$d\theta/d\lambda$	260	1175	1410	1199	970	829	721	631	552	491

15° 18.4' ROCK-SALT PRISM

λ in μ ,	1	2	3	4	5	6	7	8	9	10
$\Delta\theta$ in '	-5.2	+0.4	2.8	5.0	7.7	11.0	14.8	19.2	24.5	30.2
d in cm. . . .	-1.3	0.1	0.7	1.2	1.9	2.8	3.7	4.8	6.1	7.6
$d\theta/d\lambda$	(334)	(1600)	(1864)	1550	1330	1140	965	833	728	648
$dd/d\alpha$	0.09	0.01	0.05	0.09	0.13	0.19	0.26	0.34	0.43	0.53

λ in μ ,	11	12	13	14	15	16	17	18	19	20
$\Delta\theta$ in '	36.8	44.2	52.3	61.2	70.8	81.5	93.1	106.4	120.0	134.4
d in cm. . . .	9.2	11.0	13.1	15.3	17.7	20.4	23.3	26.6	30.0	33.6
$d\theta/d\lambda$	580	524	475	431	393	360	330	304	281	262
$dd/d\alpha$	0.64	0.77	0.92	1.07	1.24	1.42	1.63	1.86	2.10	2.35

ADJUSTMENTS OF APPARATUS

Each day's adjustments were as follows: A single Nernst glower was lit and placed in the center of the position to be occupied by the larger lamp in front of the slit. Mirror M_1 (see fig. 2) was then so adjusted that the range over which the filament was visible in it, as looked at from just in front of M_2 , was centrally situated with regard to M_2 . Next M_2 was adjusted so that the return beam centrally filled M_1 . This generally caused the image of the lamp to

* Annalen der Physik, 26, p. 120, 1908. The following were computed from the formula I on p. 130 l. c.:

λ	1.838 μ	14 μ	15 μ	16 μ	17 μ	18 μ	19 μ	20 μ	21 μ
Log n	0.1839026	0.1649292	0.1618148	0.1583802	0.1545992	0.1504420	0.1458745	0.1408578	0.1341792

fall near the slit. Finer adjustments brought the image so that its light passed centrally through the slit. The spectroscope collimator and diaphragm were then adjusted so that the beam was central both on them and on the prism. The last condition was best ascertained by looking towards the collimator through the prism and adjusting so that the filament was visible over the whole extent of the prism. The bolometer was adjusted to look centrally at the projection of the beam on the image-forming mirror and the latter adjusted to bring the image of the spectrum vertically on the bolometer.

Then, when using the 60° prism, sun-light was thrown on the spectroscope slit and the prism¹ adjusted in minimum deviation by slightly turning it back and forth, leaving it in the position where the A line, as seen in the bolometer eye-piece, was at its minimum deviation. With the 15° prism the purity of the spectrum was insufficient to show any solar lines. A Bunsen flame, colored with sodium, was used to illuminate the slit instead of sun-light and the adjustments were made by means of the D lines. The spectrometer circle was then turned to bring the A or D line central on the bolometer strip and the position was read. Energy curves (or bolographs) were started from the spectrometer positions thus determined.

After the apparatus had been thus adjusted the blower was started and readings were made of the wet and dry thermometers in the water-vapor tube before beginning observations.

OBSERVATIONS

It was originally proposed to observe alternately the energy in the spectrum of the Nernst lamps when shining through the water vapor in the large tube and immediately thereafter when shining through the spectroscope alone. It was found, however, that the curves obtained through the water vapor in the spectroscope remained so constant over the greater part of their wave-length range that in the 1916 observations they were often omitted. The change in aspect of the curves attending the above described change in path of the rays gave a measure of the absorption produced by the water vapor and carbon dioxide in the tube.

¹ Before setting up the prism it was best to give it a new coat of asphalt and slightly warm it out in the sun-light to prevent the fogging of its surfaces by the deposition of moisture from the air.

TRANSPARENCY FROM 1.2 TO 9.0 μ

In the upper portion of figure 6 will be seen a curve drawn from a bologram showing the distribution of energy in the spectrum of the lamp of Nernst glowers after the passage of its radiation through the air, carbon dioxide and aqueous vapor in the path through the spectroscope alone.

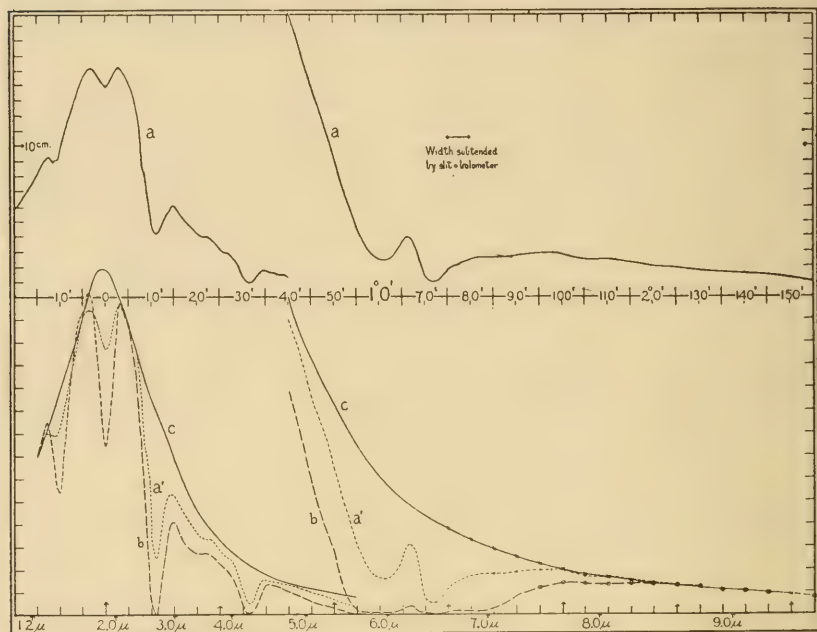


FIG. 6.—*a*, Bologram Nernst lamp, 60° rock-salt spectrum; *a'*, ditto corrected for slit and bolometer widths; ppt. H_2O , 0.01 cm.; *b*, ditto, ppt. H_2O , 0.1 cm.; *c*, black-body curve, 2,200° K.

To see whether any of the energy at the longer wave-lengths was due to energy scattered from the shorter wave-lengths, several bolograms were made with a quartz plate $\frac{1}{2}$ cm. thick inserted between the lamp and the slit. No appreciable deflection was observed beyond 4 μ , where quartz becomes opaque. Hence there is no appreciable energy at the deviations corresponding to wave-lengths greater than 4 μ contributed by radiation of shorter wave-lengths transmissible by quartz.

CORRECTION FOR SLIT AND BOLOMETER WIDTHS

When a spectrum is formed with a slit of finite width (the slits here in use were often necessarily wide), the energy at any point in the spectrum includes an appreciable range of wave-lengths depending upon the angular width of the slit. This apparent so-called impurity of the spectrum is further increased by the finite width of the bolometer. Indeed it is easily seen that the range of deviations observed by the bolometer at any point of the prismatic spectrum is equal to $2(a+b)$ where a and b are the slit and bolometer widths expressed in angular values subtended in the spectrum. In appendix I will be found the derivation of a formula for partially correcting for this impurity of the spectrum. This formula was applied in every case where the resulting correction would be of importance. Such a formula can only partially correct for errors in the readings of the maxima and minima in a spectrum. It of course cannot reproduce from a nearly continuous record, such as is shown in the upper part of figure 6, a purely line absorption spectrum such as is produced by water vapor. Such a formula is best applicable to a continuous spectrum such as would be given, for example, by a black body.

Having corrected the curve in the upper part of figure 6 for the widths of slit and bolometer, it becomes as shown at a' in the lower part of the figure. Here the ordinates of the longer wave-length portion (5 to 9μ) are magnified 10 times relatively to those of the shorter wave-length section. Curve b , on a uniform scale with a' , records the energy passing through the air, carbon dioxide and water vapor in the 117 meters additional path of the large tube. Curve c on a similar scale is the black-body curve corresponding to a temperature of $2,200^\circ$ K.

In order to obtain the amount of energy absorbed by the aqueous vapor it would be highly desirable to observe the energy first through the 117 meter path in vapor, then through the same path free of vapor. This was practically impossible. As a substitute for the latter condition, the energy was recorded with the lamp turned so as to observe its energy when passing through the spectroscope alone. With such a process the deflections at any wave-length could not be directly compared but had to be first reduced to the same scale. This was done by making the two sets of curves coincide near deviations $-5'$ and $+5'$ in spectrum regions where the many experiments of this observatory indicate no appreciable absorption by atmos-

pheric gases and vapors. Curve a' of figure 6 is an energy curve so made and it will be noted that even with the comparatively short path through the spectroscope (11.5 meters) some of the absorption bands are still quite pronounced. A black-body curve tangent to the curve a' and corresponding to a temperature of $2,200^{\circ}$ K. was thought to be the best means of representing what might be expected as the form of the energy curve were there no absorption bands present. This is curve c which is tangent to curve a' at deviations $\pm 5'$, at $100'$ to $140'$ (8 to 9μ) and nearly so at $40'$ (5μ).

In figure 7 are plotted the results obtained by dividing by values read from curve c those obtained from curves similar to a' and b . The solid points with the dashed lines connecting the mean values, belong to the class a' , and show the absorption produced by the water vapor and carbon dioxide in the path through the spectroscope alone. The aqueous vapor corresponds to 0.008 cm. ppt. H_2O , the carbon dioxide, to about 7.4 grams¹ in a column of the length of the path (11.5 meters) and a meter square in section. The curve plotted with open circles, squares and diamonds with the solid connecting line corresponds to the class b . This curve shows the absorption due to the medium contained in the path of 117 m. through the great tube. The aqueous vapor corresponds to 0.082 cm. ppt. H_2O and the carbon dioxide to 83 grams in a column of the length of the path and of a square meter in section. Probably the *increase in absorption* indicated by the increase in the area of the absorption bands of the two observed curves is more accurate than the absolute values of absorption for these involve the assumption that the black-body curve of $2,200^{\circ}$ K. would represent the distribution of energy if there was no absorption.

There is also reproduced in the dotted curve extending from 5 to about 7.7μ the work of Rubens and Aschkinass (l. c.) taken with a column of steam 30 cm. long at 100° C. and corresponding to 0.0042 cm. ppt. H_2O .

In the region shown here there are two important bands with maximum absorption according to Paschen at wave-lengths 2.73 and 4.63μ respectively due to carbon dioxide. Unfortunately it was not feasible to remove this gas from either the spectroscope or the large

¹ The total CO_2 , similarly measured, vertically from the surface of the earth outwards is about 3,000 grams.

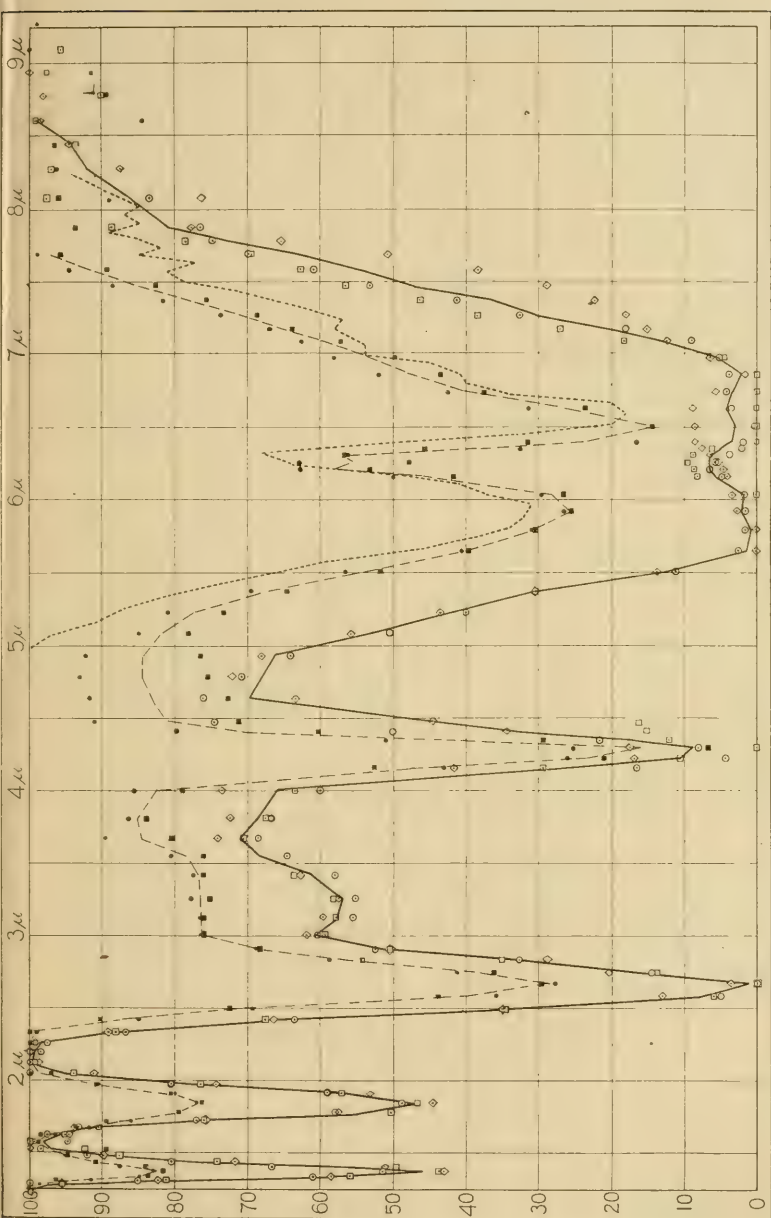


FIG. 7.—Percentage absorptions obtained with 60° rock-salt spectrum.

Lower curve. 0.082 cm. ppt. H_2O , 83 grams CO_2 in m^2 path. } Atmospheric conditions.

Middle curve, 0.008 cm. ppt. H_2O , 7 grams CO_2 in m^2 path. }

Upper curve, 0.004 cm. ppt. H_2O , 0 grams CO_2 in m^2 path. { Steam, 100° C.
Abscissae are wave-lengths, ordinates, percentage transmissions.

tube. Paschen¹ gives the following data relative to the amount of absorption in these bands:

TABLE 3.—CARBON DIOXIDE BAND 2.34 TO 2.92 μ ; MAXIMUM AT 2.73 μ

Equivalent path in cm. CO ₂ , 76 cm. pressure . . .	0.08*	0.3	7	33
Grams CO ₂ , column 1 m ²	1.6	5.9	140	650
Absorption per cent.	11	....	30	43

CARBON DIOXIDE BAND 4.26 TO 5.12 μ ; MAXIMUM AT 4.63 μ

Equivalent path in cm. CO ₂ , 76 cm. pressure . . .	0.08*	0.3	7	33
Grams CO ₂ , column 1 m ²	1.6	5.9	140	650
Absorption per cent.	29	55	88	90

* Paschen in obtaining this figure assumes with Kayser (Wied. Ann. 42, p. 310, 1891) that the CO₂ in his laboratory had a partial pressure of about 1/1000 atmosphere. In computing the values given in the present work the partial pressure given by Hann of 0.23 mm. or 3/10,000 of an atmosphere has been used, for the experiments were made under out-of-door conditions.

Remembering that there were respectively about 7 and 80 grams of CO₂ in the meter square absorbing column producing the two curves of figure 7, Paschen's results indicate that probably something like 20 per cent of the absorption in the water-vapor band at 2.65 μ and 60 to 70 per cent in that at 4.3 may be due to carbon dioxide. For the carbon dioxide band at 4.63 μ Paschen considers that 650 grams is enough to produce practically complete absorption, the 10 per cent left in the table probably being accounted for by the impurity of his spectrum. Accordingly 3,000 grams CO₂ in a vertical atmospheric column 1 meter in cross section would suffice to completely extinguish the solar energy in the band whose center appears at about 4.6 μ . It appears from Paschen's work that the absorption for 0.004 cm. ppt. H₂O in the form of steam at 100° C. and 76 cm. pressure, is about equal to that of 0.008 cm. in the form of vapor at somewhat less than 15° C. and 8 mm. partial water-vapor pressure.

The region covered by figure 7 has been further subdivided and the absorption measured is indicated in the following table. The next to the last line summarizes the data of the absorption for the whole region given in parts in the five lines just preceding. The last line summarizes the data of absorption for the whole region from 1.3 to 8.0 μ . The last value, which gives the absorption percentage for the radiation as a whole, depends greatly on the distribution of energy in the spectrum of the beam to be absorbed. In the fourth column the

¹ Annalen der Physik und Chemie, 51, p. 51, 1894.

distribution of energy in the spectrum here observed with the Nernst lamp at 2,200° K. is indicated, and this may be regarded as a measure of the "weights" of the different parts in producing the absorption value here given. If instead of a Nernst glower the sun were observed, the upper part of the table would have even greater weight, while with the earth as a radiator the lower part should have a greater weight. The relative weights in the earth's case are given in the last column and the absorption value in the footnote to the table.

TABLE 4.—ABSORPTION BY WATER VAPOR, 1.3 TO 8.0 μ

Band	Range of wave-length μ	Relative energy 2200° K. Black radiator	Percentage absorbed		Relative energy 287° K. Black radiator
			Precipitable water in cm.		
			0.008	0.082	
Ψ	1.3 to 1.75	2300	6.1	18	0
Ω	1.75 " 2.2	2150	13.6	29	0
X	2.2 " 3.2	2400	23.6	41	1
—	3.2 " 4.0	1050	21.7	37	38
Y	4.0 " 4.9	640	32.5	50	418
Z	4.9 " 5.4	210	18	42	440
"	5.4 " 5.9	150	47	85	545
"	5.9 " 6.4	120	64	97	915
"	6.4 " 7.0	110	68	97	1340
"	7.0 " 8.0	120	25	62	2570
Z	4.9 " 8.0	710	40*	73*	5810
All	1.3 " 8.0	9250	19*	34*	6267

* These figures give the percentage of radiation from the Nernst lamp (2,200°-300° K.) absorbed in the band Z (4.9 to 8.0 μ) and in the whole region 1.3 to 8.0 μ . The corresponding figures obtained by means of columns 4, 5, and 6 for a distribution of energy of a black-body radiating at the temperature of the earth (287° K.) to space (0° K.) would be 43 and 42 per cent for 0.008 cm. ppt. H₂O and 76 and 74 per cent for 0.082 cm. ppt. H₂O.

ABSORPTION DOWN TO 16 μ

With the 60°-prism spectroscope used in the work just detailed, the energy even at 9 μ had become almost too feeble for accurate measurement. From 10 μ to 16 μ recourse was necessary to the smaller dispersion and consequently greater intensity in the spectrum formed by a 15° rock-salt prism. The reduction of the corresponding observations brought many more difficulties as the detailed discussion coming will show.

Turning to figure 8, there will be seen a reproduction of a record of the deflections of the galvanometer needle which measures the amount of energy absorbed by the blackened bolometer strip, as there passes over it, under varied circumstances, the 15° -prismatic rock-salt spectrum of the lamp of 88 Nernst filaments or glowers. This record was made September 19, 1916, with 0.012 cm. ppt. H_2O in the path between the lamp and the bolometer.

The record consists of three sets of curves: first a lower, dotted, single-branched record indicating the zero of the galvanometer needle when a shutter at a temperature of about 300°K. was inserted between the lamp and the slit; second, an upper, five-branched curve,

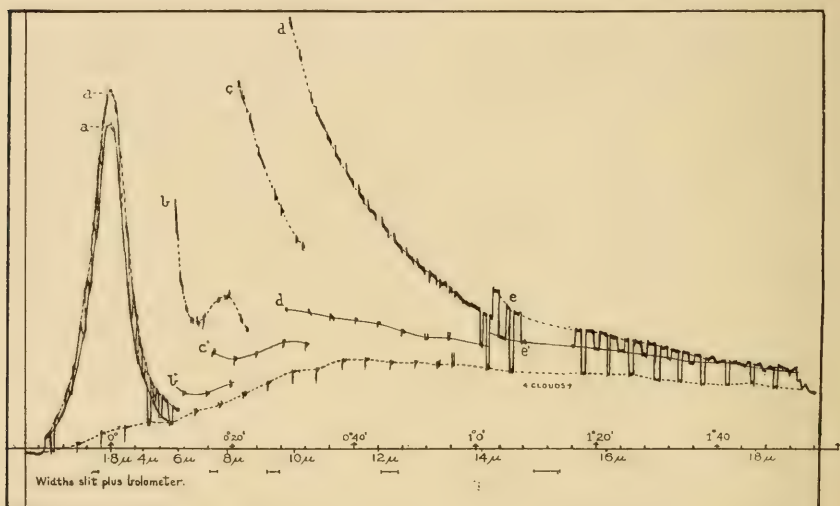


FIG. 8.—Bologram 15° rock-salt prismatic spectrum of Nernst lamp through aqueous vapor and carbon dioxide in the spectroscopic path alone. 7 grams CO_2 in m^2 path, 0.012 cm. ppt. H_2O .

abcde, the observed energy spectrum of the lamp. The branch *a* shows the rapid rise of energy to a maximum at 1.838μ and, for the present record, was made with a slit 0.67 mm. wide, the inflowing energy being further reduced $1/20$ th by a rotating sector. There is a rapid fall of energy on the right-hand or long wave-length side, and the sector was removed to allow sufficient energy to flow through the slit to produce the branch *b*; then for the branch *c* the slit was increased to 2.36 mm., for the branch *d* to 5.82 mm., and finally for the branch *e* to 10.69 mm.¹

¹ These slit-widths were obtained either by the use of brass slits of fixed widths inserted in front of the regular spectroscope slit, or by closing the latter until its jaws just touched a measured cylindrical template.

The points connected to form the third trace $a'b'c'd'e'$ were obtained by the insertion of a plane-parallel quartz plate one-half a centimeter thick, between the energy source and the slit. Otherwise the conditions were for curve $a'b'c'd'e'$ the same as for the curve $abcde$. The significance of this third curve will be presently considered.

Taking into account the widths of slit and bolometer these curves were first corrected to represent as well as possible "pure" spectrum conditions as described under the work relating to the shorter wave-lengths. See also Appendix I.

The next step was the reduction of all the branches of the two upper curves to the same scale. Provision was made to accomplish this by arranging the observations so that in the last three branches ordinates were obtained at the same abscissae for two successive slit conditions. However, when the ratio of ordinates under the wide slit to those under the narrow slit was taken, this ratio was found to progressively increase as the wave-length increased. The cause of this change, as stated in the description of the slit, remained obscure for some time until it occurred to Dr. Abbot that it was probably due to the spreading of the beam by diffraction when the narrower slit was used to produce the lower branch of the curve. As already stated and explained (l. c.) it occurred only when the beam passed through the long tube containing the water vapor and not when employing the path in the spectroscope alone. In the former case, the beam just filled the collimator mirror and diffraction caused it to spread off the mirror. In the latter case the beam considerably more than filled the mirror and the diffraction produced no harmful result.

This disturbance, therefore, rendered difficult the determination of diaphragm values for the reducing of the various parts of the curve to the same scale. With the spectroscope alone no trouble was found, for the slit ratios as measured mechanically and by means of the deflections agreed closely and the energy curve over the whole range of wave-lengths could be reduced to a uniform scale. It was thought best on the whole to use the same slit ratios for the tube work that were used with the spectroscope alone. To avoid error in the tube work as far as possible the overlapping parts of curves made with the smaller slit were rejected. It might, however, be feared that some error from diffraction affects the tube work even with wide slits. This matter will be treated later, and such errors will be shown to be probably negligible.

It was next necessary to reduce the curves "with" and "without" the water vapor to a common scale. It had been intended to do this by comparing the heights of the branches of region *a* and making these heights in the ratio which the higher dispersion work already described on this region indicated. This method had to be abandoned not only because of the difficulty of reducing the successive portions of the curve to the same scale as *a*, but also because of the great sensitiveness of the branch *a* to change in the amount of vapor. For the branch *a*, extending from say about 1 to 4 μ , includes several important water vapor absorption bands, namely, ϕ , ψ , Ω , and X, besides several smaller bands. These bands, because of the impurity of the spectrum, are not indicated in the smooth contour of this maximum. Their existence is felt, however, by its rapidly decreasing height with increasing amount of absorbing vapor as may be seen in figure 8. These separate bands may be seen in the result with the 60° prism shown in figure 7. Only the great band between 5 and 8 μ is noticeable in the impure spectrum recorded with the 15° prism.

The portion of the energy curve in which the greatest interest centers is that part where the wave-lengths are greater than 10 μ , or in other words, of greater wave-length than the part treated in the work with the 60° prism. Fortunately this portion was obtained generally without change of slit over its whole range. After correcting for "field light," as will be presently described, all curves were put on the same scale as follows: The assumption was made that there is no absorption by water vapor between the wave-lengths 9 and 10 μ .

The evidence for the validity of the assumption of no absorption of energy between 9 and 10 μ by aqueous vapor is cumulative and as follows: The work with the 60° rock-salt prism which formed the first part of this research indicated no absorption there. Rubens and Aschkinass found certainly less than 5 per cent absorption with *steam*.¹ Further support comes from the work of Langley,² who found at 10.7 μ , from a comparison of high and low sun (air-mass = 3.76) observations, complete transmission of the solar energy of this wave-length. The decreased transmission which he found for greater air-masses was without doubt due to the smoky atmosphere of Allegheny (Pittsburgh, Pennsylvania, U. S. A.). Langley's results are confirmed by similar work on the sun done here and pre-

¹ *Annalen der Physik und Chemie*, 60, p. 418, 1897.

² *Memoirs National Academy of Sciences IV*, p. 159, 1888.

sently to be described. Additional confirmation is given by the agreement in form from 9 to $13.5\ \mu$ of curves taken here with a range of from 0.003 to 0.028 cm. ppt. H_2O . All the energy curves taken through the spectroscope alone (which involved a range of between 0.003 and 0.012 cm. ppt. H_2O) were reduced and carefully compared. Upon reducing to the same scale between 9 and $10\ \mu$ they showed a remarkable agreement even over the whole range from 9 to $13.5\ \mu$ indicating no change in transmission of energy within this range of wave-lengths when the ppt. H_2O increased from 0.003 to 0.012 cm. A yet later set of observations taken on a cold winter day through the long tube with the total ppt. H_2O equal to 0.028 cm. also agreed over this range. It would be very improbable that the percentage absorption would be uniform over the range from 9 to $13.5\ \mu$ unless the absorption over this whole range is zero. Any departure from such a uniform absorption would have tended to cause the curves to diverge at the longer wave-lengths.

In accordance with the well-grounded assumption just discussed all curves were made to agree in intensity between the wave-lengths 9 and $10\ \mu$.

DIFFRACTION EFFECT

It has been stated that with the energy curves made with the beam passing through the spectroscope alone no diffraction effects were noted in determining the diaphragm or slit ratios. It was also stated that the curve just referred to taken with the minimum amount of aqueous vapor (0.028 cm. ppt. H_2O) in the path through the great tube coincided in form from 9 to $13.5\ \mu$ with those taken through the spectroscope alone. This justifies the inference that the width of the slit (10.69 mm.) used from 9 to $13.5\ \mu$ in the "tube" observations was sufficient to avoid diffraction losses. Beyond this wave-length the energy in the tube curves is practically all depleted by the carbon-dioxide band central at $14.75\ \mu$ but which produces an appreciable effect, according to Rubens, all the way from 12 to $16.5\ \mu$. Its effect is most important from 14 to $15.5\ \mu$.

STRAY LIGHT

Before proceeding with the discussion of the transparency of aqueous vapor attention must be directed to the most troublesome source of error of all. The intensity of energy observed at any point in a spectrum will be due in part to the true energy of the wave-length considered and in part to energy scattered there from other regions of the spectrum. Naturally a portion of energy proper

to the wave-length under observation is lost by scattering into other parts of the spectrum. Even with the slit closed the field may not appear dark because of stray light in the room. General field light like this is not very objectionable, for it is present both when observing the zero of energy with the shutter interposed in front of the slit, and when measuring the intensity in the spectrum, and is eliminated.

In a well-designed spectroscope of moderate dispersion, producing a spectrum the intensity in which ranges 100- or even 1,000-fold, scattered light may cause no trouble. But when, as in the present research, the whole spectrum from the violet to $20\ \mu$ is contained in a dispersion of only about $1\frac{1}{2}$ degrees and the intensities range 100,000-fold, this disturbance became exceedingly troublesome. In the solar spectrum at $10\ \mu$, for instance, the field-intensity due to scattered energy may be over 100 times the true energy belonging there. The safest expedient under such circumstances is to use a sifting train¹ or auxiliary spectroscope forming a spectrum on the slit of the main spectroscope and so adjusted as to allow only that part of the spectrum desired to pass through the main slit. The scattered light of other wave-lengths is then deviated in the main spectroscope to its proper place in the spectrum formed, and is negligible.

A very large proportion of the time and labor consumed in the research was devoted to the elimination of errors from this stray light, but it would seriously break the continuity of the exposition to explain it in full here. Accordingly the subject has been relegated to Appendix II, but the main principles of the method employed to correct for stray light follow.

Since nearly all of the radiation of a Nernst glower is of less wave-length than $4\ \mu$, it follows that nearly all of the stray light produced by scattering is transmissible by quartz. Hence if the interposition of a quartz plate at a point beyond $4\ \mu$, where the ordinate of the energy curve is y_1 , reduces the ordinate to y_2 , the true ordinate proper to the ray which should be found there does not exceed $y_1 - y_2$. But since a quartz plate reflects approximately 15 per cent of the rays at wave-lengths found in the Nernst glower spectrum above $4\ \mu$, it is clear that the ordinate y_2 , which is due wholly to stray light transmissible by quartz, would have reached $1.18y_2$ if the quartz had produced no reflection. Hence the true radiation could not have exceeded $y_1 - 1.18y_2$. Although rays of less wave-length than $4\ \mu$,

¹ Memoirs National Academy of Sciences, IV, p. 159, 1888.

since they constitute nearly all of the energy of a Nernst glower, and still more its energy after water-vapor absorption, must furnish most of the stray light, still it cannot be assumed that the stray light of longer wave-lengths than $4\ \mu$ is negligible. Accordingly to the ordinate $1.18y_2$ there must be made another addition, which we may call Σy , representing the stray light of all wave-lengths non-transmissible by quartz. By a special research the quantity Σy has been determined for each place in the spectrum, as will be explained. The corrected ordinate now becomes $y_1 - 1.18y_2 - \Sigma y$. Finally each ray is, on the other hand, depleted by sending stray light to all parts of the spectrum. But as will be shown the depletion is so nearly the same proportion of the intensity, namely, about 3 per cent, for all the wave-lengths here considered that to correct for it is merely to multiply all ordinates by the same multiplier, which may be omitted. The increase in scattered energy, Σy , over 1.18 times that observed by the insertion of the quartz plate, ranges from 2 to 11 per cent according to the angular deviation. In addition its amount varies over a range of about 2 per cent for the changes in the amount of absorbing vapor occurring in this research.

All the observations taken during 1916 and 1917 were corrected for stray light by the process detailed in Appendix II. The entire absence of appreciable stray light in the part of the research made with the 60° prism unfortunately led to a false feeling of security in the first work with the 15° prism, and in much of the earlier work with it no field-light experiments were made. Accordingly the following indirect way was resorted to for its elimination: The 1916-17 work showed that with the carbon dioxide present in the long tube no energy at wave-lengths longer than $15\ \mu$ should reach the bolometer. Accordingly all of the considerable deflection observed there could be considered as stray light. The stray light for shorter wave-lengths was assumed to bear the same ratio to this that the ordinates at the corresponding deviations of the stray light curve of figure 18 do to each other. This involves building up an ever increasing correction from a somewhat small observed value. However, fortunately the larger in absolute amount it becomes, the less its importance, for it becomes a smaller fraction of the total observed deflection. The validity of this procedure is perhaps shown by the depths thus obtained in the great band at $7\ \mu$ where the somewhat large deflection observed should be nearly all stray light.

Before considering further troubles we will pass to a consideration of the results as shown in figures 9 and 10. The form of the observations was already made familiar through figure 8.

DESCRIPTION OF FIGURE 9

Running across the figure will be noted a heavy, black, smooth curve just above which are indicated the wave-lengths. This is a black-body spectrum curve of a source at $2,200^{\circ}$ K. radiating to one at 300° K., as computed from Planck's formula with C_1 equal to 9.23 and C_2 equal to 1.445 for λ in cm. for a 15° rock-salt spectrum. The curve is in three sections, the ordinates of the second and

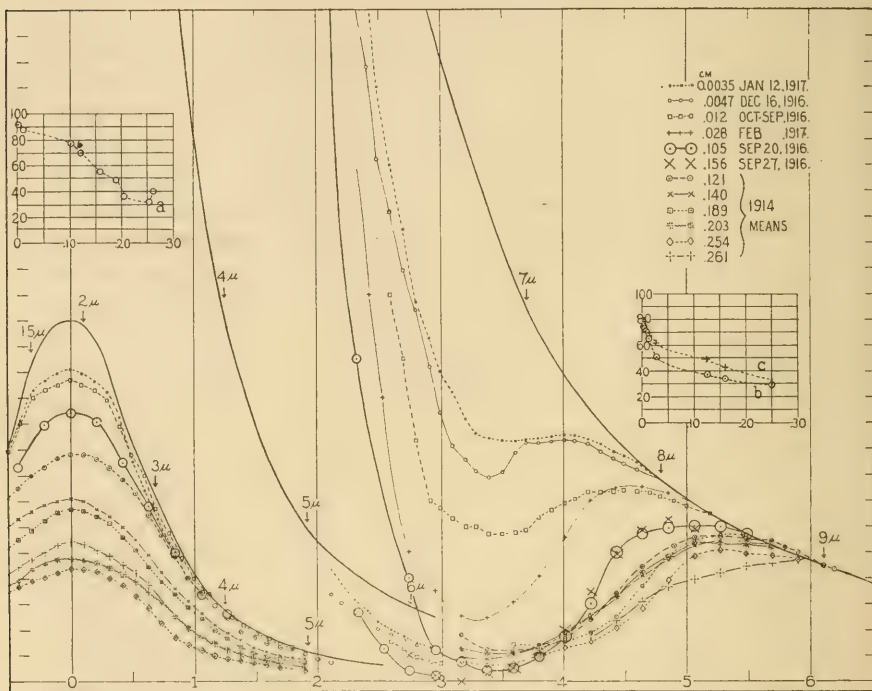


FIG. 9.—Energy curves showing the absorptions produced by water vapor in the 15° rock-salt prismatic spectrum of the Nernst lamp. Ordinates are intensities of energy. Abscissae are proportional to prismatic deviations from 1.8μ . In curves *a*, *b*, *c*, the ordinates are percentage transmissions. Curve *a* gives the transmission percentages for the complex beam including wave-lengths between 1.25μ and 3μ in the lamp spectrum; curve *b*, ditto for between 5μ and 9μ ; curve *c*, ditto but for black body at 287° K.

third section being multiplied relative to the first by 5 and 50 respectively.¹ The plate distances proportional to prismatic devia-

¹ The energy curve is formed for a body radiating from $2,200^{\circ}$ K. to one at 300° K. because the deflection observed with the lamp may be considered as due to the radiation from a body at $2,200^{\circ}$ K. radiating to the bolometer and the deflection due to the insertion of the screen at 300° K. as the radiation

tions, taking as zero the deviation at 1.838μ , are indicated by the numbers at the bottom of the plot.

Underneath these three branches of the black-body curve computed for a temperature corresponding to the "black-body" temperature ($2,200^\circ \text{ K.}$) of the Nernst lamp will be found curves representing the energy spectrum of the lamp through increasing amounts of aqueous vapor. These amounts, as indicated in the table on the plot, range from 0.0035 to $0.012 \text{ cm. ppt. H}_2\text{O}$ when observed through the spectroscope alone; and from 0.028 to $.261$ when observed through the tube. Each curve is the mean of several sets of observations.

For the curves with 0.0035 to $0.012 \text{ cm. ppt. H}_2\text{O}$ there were 7 grams carbon dioxide, and in all the others, except the one with $0.254 \text{ cm. ppt. H}_2\text{O}$, there were 83 grams carbon dioxide in a 1 m. sq. path ; for that one there were 160 grams. For a discussion of its influence on the absorption in the region of figure 9 see the work with the 60° prism.

In the small figure in the upper left-hand corner will be seen a curve (marked *a*) which shows the percentage change in area of the maximum between 1.25 and 3μ plotted against the $\text{ppt. H}_2\text{O}$ in cm. as abscissae. In the other small figure the similar function is plotted for the region between 5 and 9μ . Curve *b* was read from the large plot and is for a distribution of energy for a body like the Nernst lamp at $2,200^\circ \text{ K.}$ Curve *c* was computed for a distribution of energy for a body at a temperature of about 287° K. , which is about the mean temperature of the earth. Table 6 gives more in detail the data from which curves *b* and *c* were drawn. It will be noted in the main curves of figure 9 that between 6 and 7μ the absorption is practically complete for $\text{ppt. H}_2\text{O}$ of 1 mm. or more.

from a body at 300° K. to the bolometer. Hence the observed intensity of the lamp is really the difference of the deflections in the two cases and should therefore be compared with the black-body curve as drawn. The ratios of the radiation from a body at 300° K. to that from one at $2,200^\circ \text{ K.}$, both radiating to absolute zero, are shown in the following table:

TABLE 5.—RATIO OF RADIATION FROM A BODY AT 300° K. TO THAT OF A BODY AT $2,200^\circ \text{ K.}$

Wave-length. Ratio.....	2μ 1×10^{-8}	6μ .00067	8μ .0031	10μ .0075	12μ .013	14μ .020	16μ .026	18μ .033	20μ .038
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To a wave-length of about 7μ the radiation of the shutter is negligible. At 6μ the observed radiation of the lamp needs to be increased $1/10$ of 1 per cent and at 20μ by 4 per cent in order to represent what it would be if radiating to absolute zero.

TABLE 6.—WATER-VAPOR ABSORPTION 5 to 9 μ

Range of wave-length	Relative energy black-body spectrum.		Percentage absorption						
			Precipitable water in cm.						
	2,300° K. Nernst lamp	287° K. Earth.	.0035	.0047	.012	.028	.125	.16	.25
5-6 μ	1690	142	18	22	25	.43	.55	.59	.65
6-7 μ	947	242	48	54	69	.85	.95	.95	.95
7-8 μ	537	315	15	19	34	.42	.66	.76	.83
8-9 μ	388	360	00	00	02	02	08	13	35
5-9 μ	3562	1059	..	..	..	..	..	..	..
5-9 μ	Lamp	....	24	27	35	40	63	66	71
5-9 μ....	....	Earth	18	21	30	38	51	57	67

DESCRIPTION OF FIGURE 10

Figure 10 is a continuation for wave-lengths longer than 9 μ of the curves shown in figure 9. The scale of abscissae is much more condensed. The ordinates of the two right-hand branches are magnified 10-fold relative to the first or left-hand branch. The extreme right-hand curves represent only the work of 1916-17. As there are so many observations it was thought best to shift the abscissae of the 1916-17 work five deviation units to the right to avoid confusion.

As in figure 9, so in figure 10, above the first two branches is given the computed black-body curve corresponding to the effective temperature of the lamp. This will be presently considered. Just below it is another heavy line. It represents the mean of observations of the last three years mainly through the spectroscope alone and within a range of water vapor from 0.003 to 0.028 cm. ppt. H_2O . Within this small range of ppt. H_2O no systematic differences were found.

Observations on a cold day were desired for three purposes: First, to permit the comparison of the curve just described with one through the tube with an amount of vapor of the same order. Generally the tube contained more than 10-fold this amount of water vapor. Second, from a comparison with the mean curve just described to form some estimation of the effect of carbon dioxide. It was supposed that on a very cold day the absorption due to the water vapor in the tube would be so nearly the same as with the observations through the spectroscope alone that the differences would be negligible and thus the increased effect of the carbon dioxide in the tube would be unmasked. Its effect, since its amount in the tube is probably quite constant from day to day, could be then eliminated from the aqueous vapor effects. Third, if coincidence of the two curves taken

with different slit widths occurred, it would serve to assure the absence of errors from diffraction in the tube observations.

Such a cold day was finally obtained in February, 1917, with only 0.028 cm. ppt. H_2O in the optical path. An excellent set of observations was obtained and the mean result of the day, so far as it diverged from the curve of the spectroscope alone, is plotted with simple crosses under the extreme right curve (1916-17 observations). It shows: First, that an increase in water vapor from 0.003 to

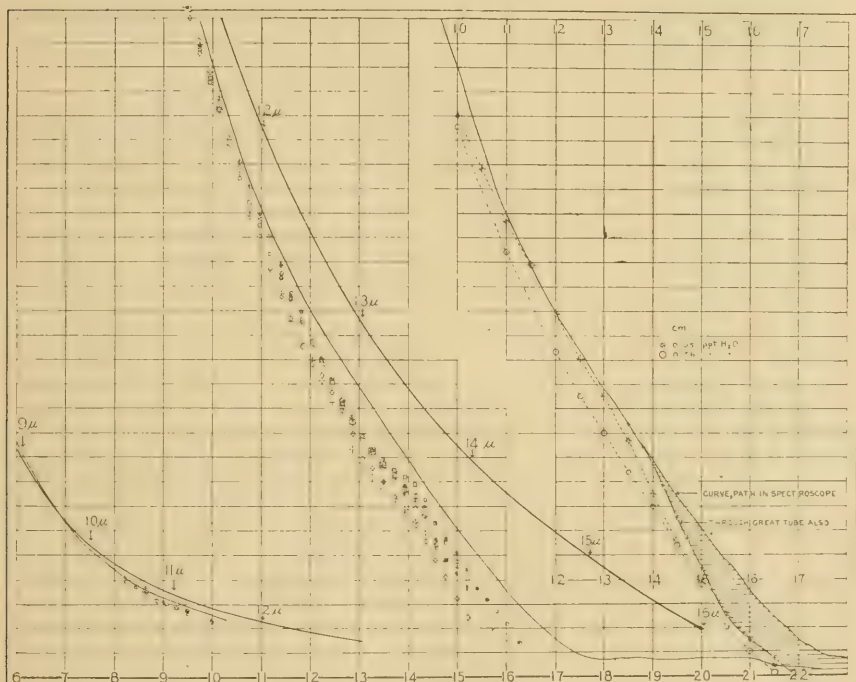


FIG. 10.—Energy curves showing the absorptions produced by water vapor in the 15° rock-salt spectrum of the Nernst lamp. Ordinates are intensities of energy. Abscissae are proportional to prismatic deviations from 1.8 μ . Unless otherwise stated, dates are as indicated in Figure 9.

0.03 cm. (10-fold) produces no appreciable change in transparency of the region from 9 to 13.4 μ . Second, that beyond from 13.4 μ the additional carbon dioxide contained in the tube becomes very effective, and produces practically complete absorption at about 14.6 μ . The cross-hatched portion shows the proportion of energy cut off by absorption. This may be assumed to be the added effect due to the carbon dioxide in the tube over that present in the spectroscope.

It has already been noted in the section on "Diffraction Effects" that the coincidence (up to the region of the carbon dioxide band) of

the curves taken with and without the tube confirmed the view that diffraction with the wide slits used in this region causes little error in the tube work. In table 7 will be found the percentages of absorption at various wave-lengths greater than $9\ \mu$ as indicated from all the experiments. The values are grouped with regard to the quantity of ppt. H_2O traversed by the beam, but the results of the years 1914 and 1916-17 are kept separate. The lowest line of table 7 comes from observations of Rubens and Aschkinass in which they used an absorbing tube containing 75 cm. of steam at 100°C . This contained .045 grams ppt. H_2O .

TABLE 7.—WATER-VAPOR ABSORPTION 9 to $14\ \mu$

cm. ppt. H_2O	$9.0\ \mu$	$10.0\ \mu$	$11.0\ \mu$	$11.5\ \mu$	$12.0\ \mu$	$12.5\ \mu$	$13.0\ \mu$	$13.5\ \mu$
Up to 0.03.....	0	0	0	0	0	0	0	0
.10.....	0	0	0	..	2	0	3	15
.15 (1914).....	0	0	..	2	3	8	14	15
.16 (1916-17).....	0	0	..	..	8	11	15	21
.25 (1914).....	0	..	..	3	8	13	24	26
.045 rubens, steam....	5	6	6	8	12	18	13	25

NOTE: 0 indicates no effect detected.

Although Rubens and Aschkinass' work shown in figure 11 was done in a purer spectrum it will be noted from the lines marked *s* in the plot, that a wide range of angular deviation was subtended in the spectrum by the widths of the bolometer and the slit. Not even in their work, and still less in the present research, could the line detail which doubtless exists in the water-vapor bands be expected to show. Referring to the table it may be seen that, as in the observation at smaller wave-lengths made with the 60° prism, the same amount of water absorbing (A) in the form of steam at 76 cm. pressure and (B) at the comparatively low pressure of the order of 1 cm. which prevails under atmospheric conditions, exercises much greater absorption in the form of steam.

COMPARISON OF NERNST LAMP WITH BLACK-BODY SPECTRUM

Down to wave-length $10\ \mu$ the curve computed from Planck's formula for black-body radiation from a source at $2,200^\circ\text{K}$. radiating to a black body at 300°K . shows no remarkable departure from the Nernst lamp spectrum, when due allowance is made for the absorption bands. From that point on the greater wave-lengths the observed radiation of the lamp systematically falls below that of the black-body curve. The black body curve as plotted in figure 10

was made to agree with the other curve between 9 and 10 μ and allowance has been made in it for the absorption and reflection losses from the rock-salt prism and plate, as computed in table 1.

TABLE 8.—COMPARISON OF NERNST LAMP AND BLACK-BODY SPECTRUM

Wave-length μ	11	12	13	14	15	26	52	108
Percentage drop of lamp below black-body radiation	9	15	20	41	86	...	...	...
Excess of transmission of lamp black over that at 10 μ	4	8	11	14	17	47	61	62

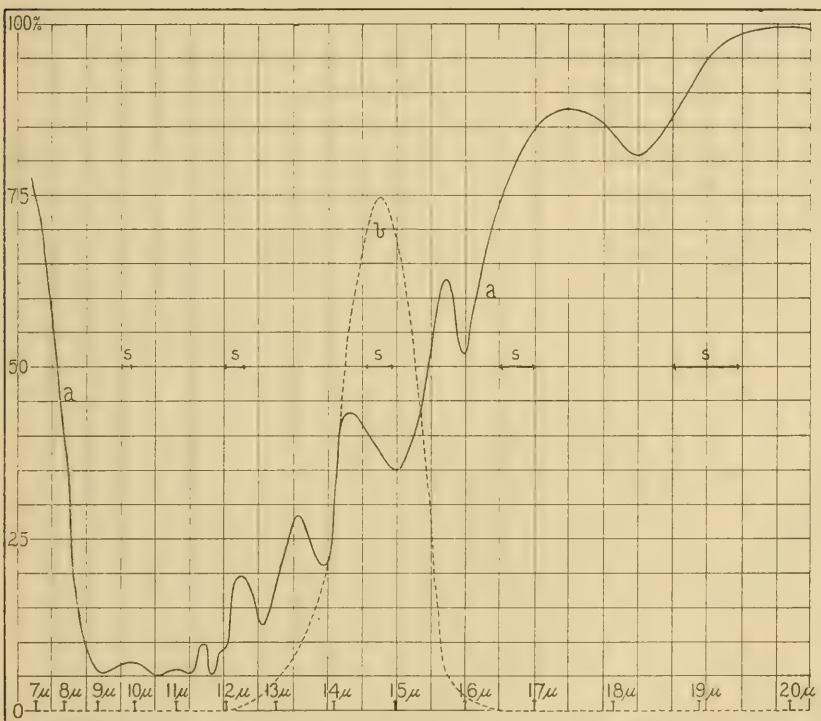


FIG. 11.—Ordinates are percentage absorptions, wave-lengths are indicated at the bottom of the figure. Curve *a*, 75 cm. steam, 76 cm. pressure, 0.045 ppt. H₂O. Curve *b*, 20 cm. CO₂, 76 cm. pressure. Work of Rubens and Aschkinass, *Annalen der Physik und Chemie*, 64, p. 598, 1898.

In the second line of the table are given values for the percentage excess of transparency of lamp black over that at 10 μ . The values were obtained with candle smoke, for a layer containing 1.8 mg. per cm². The figures are principally interpolated from values given

by Rubens.¹ In view of these figures it seems possible that the divergence of the observed Nernst lamp spectrum curve from the computed black-body curve may be partly due to the increasingly incomplete absorption of the rays by the bolometer strip. A part of the divergence is surely due to carbon-dioxide absorption. Although the experiments do not indicate any absorption by water-vapor less than 0.03 cm. ppt. H_2O , they are not quite conclusive. Owing to the impurity of the spectrum, fine line absorption, like that which Abney photographed in $\rho\sigma\tau$, may occur here undetected, and it may possibly produce its complete effects with very minute quantities of water vapor. If so, a part of the discrepancy may be due to water-vapor absorption. Finally, it is not certain that the two energy curves should coincide, for the Nernst lamp may depart widely from being a perfect radiator.

It will be noted that when observed through the spectroscope alone energy from the lamp is found beyond $16\ \mu$ even after allowance is made for the field light. The lamp curve is the mean of many observations and no doubt is felt that there is some kind of energy here. Although there may be in it some field light a return of energy is to be expected in this spectrum region beyond the carbon dioxide found where the work of Rubens indicates increased transparency of water vapor.

ATMOSPHERIC TRANSMISSION OF SOLAR ENERGY BETWEEN 9 AND $14\ \mu$

Even with the maximum amount of water vapor possible in the tube work (0.26 cm. ppt. H_2O) the transparency observed between 9 and $14\ \mu$ had appeared to be very great. It was thought worth while to attempt a measure of this transparency between 9 and $14\ \mu$ by observing the amount of energy transmitted from the sun through the earth's atmosphere for various air masses. In this way there would be brought about a several-fold increase of the amount of absorbing vapor in the path. Indeed at the maximum this amounted to 3 cm. ppt. H_2O .

Reference has already been made,² in discussing the transparency of this wave-length region to the remarkable early work of Mr. Langley. As far as air-mass 3.76 practically no absorption was found by

¹ Verhandlungen Deutsche Physikalische Gesellschaft, i3, p. 88, 1911. His values are at $2\ \mu$, 0.5 per cent transmission; $4\ \mu$, 8.6; $6\ \mu$, 16.0; $12\ \mu$, 37.6; $26\ \mu$, 76.7; $52\ \mu$, 91.3; $108\ \mu$, 91.5.

² S. P. Langley, The Solar and the Lunar Spectrum. Memoirs National Academy of Sciences, IV, p. 159, 1886.

him near wave-lengths 8.8μ and 10.7μ . The apparent decrease in transmission for greater air-masses he attributed to the smoky atmosphere prevalent at Pittsburgh. The great increase in sensitiveness and accuracy of the present day spectro-bolometric apparatus made it seem worth while to repeat these observations.

The scattered light, which in the spectrum of the Nernst lamp was troublesome, becomes absolutely prohibitive here in a directly formed 15° -prismatic rock-salt solar spectrum. At 10μ with the large galvanometer deflection of 20 cm., practically all this deflection remained, and was therefore field light, upon the insertion of the quartz plate. In the case of the Nernst-lamp spectrum at this wave-length only 16 per cent of the deflection was found to be false. Langley eliminated the stray light by using a sifting train, but this was not feasible in the present case. Dr. Abbot suggested the use of a screen of solid iodine, which Coblenz' work¹ showed to be opaque to the visible radiation and increasingly transparent for the longer wave radiation. Accordingly Dr. Abbot with Mr. Aldrich and the writer prepared two plane parallel rock-salt plates 0.65 and 0.34 cm. thick. These were uniformly heated, flakes of iodine placed on one, the other plate quickly placed on top and the two plates squeezed together. After several attempts a thin, fairly uniform film of iodine was thus obtained which micrometer measures showed to be between 0.005 and 0.007 cm. thick.

TRANSPARENCY OF IODINE

Although the direct measures on the solar spectrum were made first, it is perhaps proper to discuss here the later measures on the transmission of the iodine film. The measurement of this is not so simple as might at first be thought, again because of the scattered light. No separate allowance will be made here for the light reflected from the rock-salt plates used to protect the iodine film. The effect of the insertion of the screen as a whole is wished.

The observations consisted in making an energy curve of the 15° -prismatic rock-salt spectrum of the Nernst lamps as usual, except that every few seconds the iodine screen was inserted, then the iodine screen with the quartz plate, then the quartz plate alone, then all screens removed. The significance of the respective deflections measured were as follows when the plate was inserted at wave-length λ greater than 4μ : λ_x is used to signify the wave-length.

(a) Lamp alone: Energy of λ_x + scattered energy of $\lambda < 4 \mu$, + scattered energy of $\lambda > 4 \mu$.

¹ Physical Review 16, p. 72, 1903.

(b) Iodine screen: Energy of $\lambda_x \times$ transmission I for $\lambda_x +$ scattered energy of $\lambda < 4 \mu$, greatly diminished by opaqueness of I for $\lambda < 4 \mu$, + scattered energy of $\lambda > 4 \mu \times$ absorption for it of I .

(c) Iodine and quartz: Scattered energy of $\lambda < 4 \mu$, greatly diminished by opaqueness of I for $\lambda < 4 \mu$, and diminished by reflection from surfaces of quartz.

(d) Quartz: Scattered energy of $\lambda < 4 \mu$, diminished by reflections from surfaces of quartz.

The point especially to be noted is that the "field-light" is not the same in the two deflections (a) and (b) whose quotient would give the transmission of the iodine screen if there were no field light. Before taking the quotient (b)/(a) it was necessary to subtract

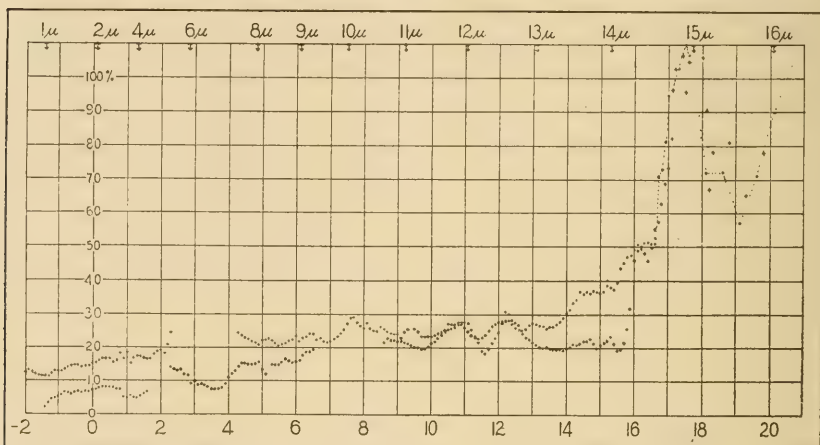


FIG. 12.—Transparency of iodine film about 0.006 cm. thick. Abscissae are proportional to deviation distances on plate from 1.8μ . The wave-lengths in microns (μ) are indicated at the top of the figure. Ordinates are percentage transmissions.

from (b), (c) + 1.17 (c) + light scattered from other wave-lengths greater than 4μ and from (a), (d) + 1.17 (d) + light scattered from other wave-lengths greater than 4μ (see section on field light). Due allowance was computed for all field light as discussed in the Appendix II.

Figure 12 shows graphically the results of the two bolographs. Unfortunately the intense heat from the 44-glowler Nernst lamp upon the iodine screen only about 10 cm. away, despite the protection of the rock-salt plates caused an evaporation of the iodine film. This is probably the cause of the discrepancy in height between the two curves in the figure. It should be remembered that the galvanometer

deflections with the iodine screen in, after subtracting the field light, were of course very small for wave-lengths less than 9μ partly because of the opaqueness of the iodine itself and partly because of the great water-vapor band preceding 9μ .

SOLAR OBSERVATIONS

Returning now to the observations on the sun, the following energy curves were made with the assistance of Dr. Abbot and Mr. Aldrich:

Bgms. I and V. Solar spectrum made with apparatus prepared for North Carolina solar-constant work. Bgm. I taken at hour angle

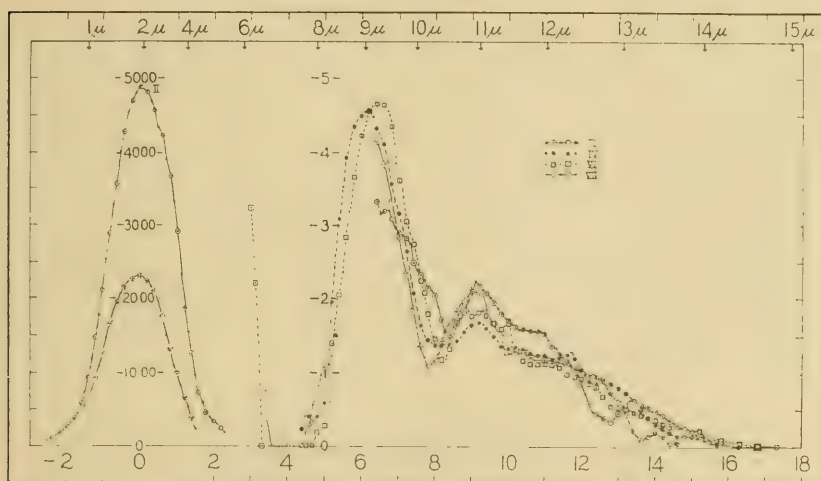


FIG. 13.—Bolograms of solar 15° rock-salt spectrum. Wave-lengths are at the top of the plate.

Bgm. II, air mass 1.5, ppt. H_2O 0.7 cm.

Bgm. IV, air mass 2.1, ppt. H_2O 1.1 cm.

Bgm. VI, air mass 3.0, ppt. H_2O 2.0 cm.

Bgm. VII, air mass 4.1, ppt. H_2O 3.0 cm.

$1^{\text{h}} 42^{\text{m}}$ W., air-mass 1.3, for purpose of determining by the depths of the water-vapor bands ρ and ϕ the amount of aqueous vapor in the path of the sun's rays through the atmosphere. These bands have been calibrated (see *Astrophysical Journal* 35, p. 149, 1912) against known amounts of water vapor.

Bgm. II. Solar spectrum made with spectroscope as used in the tube work, but with the iodine screen in front of slit. H. A.

$2^h 38^m$ W., air-mass 1.5. Proper observations were made to eliminate the field light.

Bgm. III	H. A. $3^h 27^m$ W., $m=1.8$,	similar to Bgm. II
Bgm. IV	3 55	2.1, similar to Bgm. II
Bgm. V	4 21	2.4, similar to Bgm. I
Bgm. VI	4 47	3.0, similar to Bgm. II
Bgm. VII	5 15	4.1, similar to Bgm. II

The amounts of water vapor for the various bolograms obtained directly for Bolograms I and V and by interpolation for the others were:

Bgm. I	0.6 cm. ppt. H_2O	Bgm. V	1.4 cm. ppt. H_2O
Bgm. II	0.7 cm.	Bgm. VI	2.0 cm.
Bgm. III	0.9 cm.	Bgm. VII	3+ cm.
Bgm. IV	1.1 cm.		

The observations on the long-wave-length spectrum of the sun will be found reproduced in figure 13 after due allowance for slit plus bolometer widths and field light.

Again the evidence indicates a great transparency for the aqueous vapor in the atmosphere from the wave-length 9μ to perhaps 12 or 13μ . No systematic decrease in the heights in this region of the energy curves with increasing aqueous vapor is found.

The band central at 10μ , probably due to ozone (Ladenburg and Lehman, *Ann. der Phys.* 21, p. 305, 1906), is the only place within this wave-length region which shows a consistent decrease of energy with increasing air-mass.

SUMMARY OF RESEARCHES ON ATMOSPHERIC ABSORPTION OF RADIATION

A. Water Vapor. Wave-lengths less than 2μ :

(1) Actual atmospheric conditions; molecular scattering; banded absorption.

B. Water Vapor and Carbon Dioxide. Wave-lengths 1.2μ to 9μ .

(1) Laboratory conditions approximating atmospheric conditions as to temperature and pressure. Temperature, 20° to 30° C., total pressure 76 cm., partial pressure of aqueous vapor about 1 cm.

(2) Steam, 100° C., total pressure=partial pressure=76 cm.

C. Water Vapor and Carbon Dioxide. Wave-lengths 9 to 14μ .

(1) Temperature and pressure conditions as in B (1).

(2) Temperature and pressure conditions as in B (2).

D. Steam, 76 cm., 100° C. Wave-lengths greater than 20μ .

E. Liquid Water.

(1) Wave-length less than 2μ .

(2) Wave-lengths 1 to 8μ .

(3) Wave-lengths 1 to 18μ .

F. Atmospheric Absorption of Solar Energy. 9 to 15 μ .

G. Collected Results on Atmospheric Absorption for Long-wave Radiation.

H. Subsidiary Investigations.

(1) Corrections for slit and bolometer widths.

(2) Field energy due to scattering.

(3) Transparency of iodine.

(4) Comparison of Nernst-lamp spectrum with that of black-body.

It is proposed first in this summary to indicate the information available on the absorption in aqueous vapor, not only as obtained in the present research, but also as selected from the work of others.

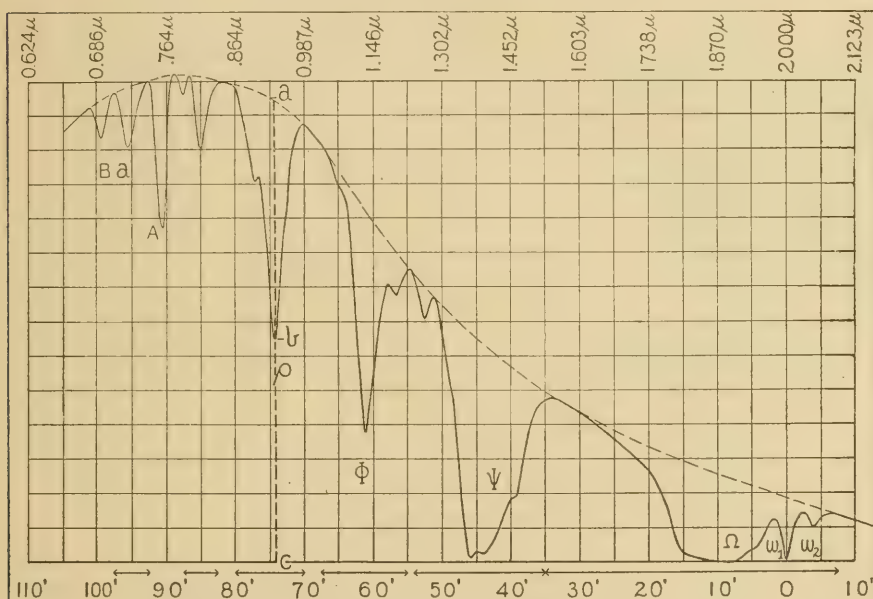


FIG. 14.—Contour solar energy-curve, 60° ultra-violet glass prism. Region of atmospheric absorption bands.

A. ABSORPTION IN WATER VAPOR, WAVE-LENGTHS LESS THAN 2 μ

(1) ATMOSPHERIC CONDITIONS

The region from 0.6 μ to 2.1 μ contains the absorption bands due to atmospheric water vapor and oxygen which chiefly affect the incoming energy from the sun. For wave-lengths less than 0.6 μ , except for a slight absorption due to a large number of small lines in the neighborhood of the D lines, the losses are due principally to molecular scattering. These losses are fully described in the following references:

"Avogadro's Constant and Atmospheric Transparency," *Astrophysical Journal*, 40, p. 435, 1914.

"The Transparency of Aqueous Vapor," *Astrophysical Journal*, 42, p. 394, 1915.

"Atmospheric Transparency for Radiation," *Monthly Weather Review*, 42, p. 2, 1914. (See also *Meteorologische Zeitschrift*, 6, p. 270, 1914.)

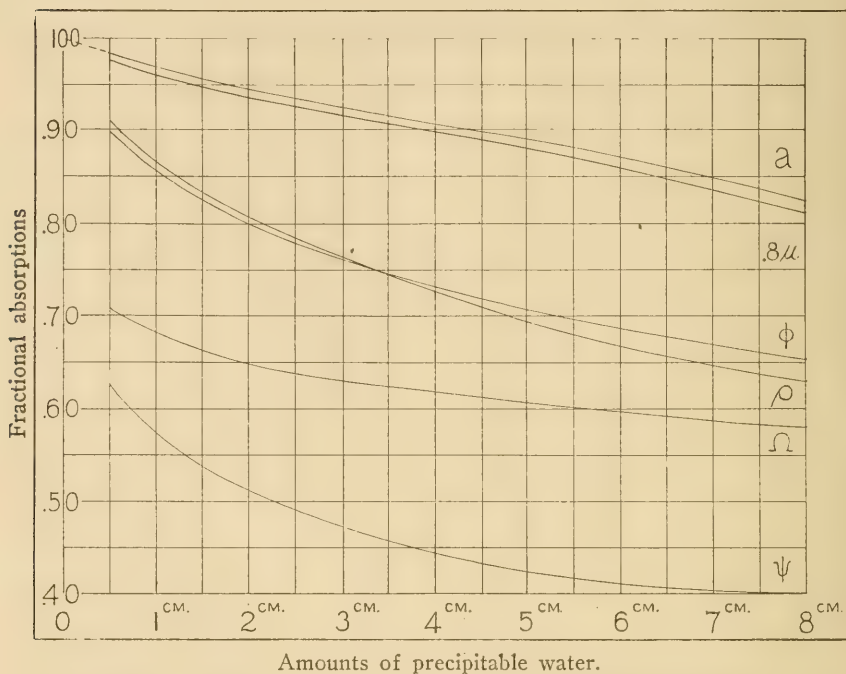


FIG. 15.—Fractional absorption of energy by water-vapor bands.

From the second of the papers just cited is reprinted figure 14 indicating the atmospheric bands between 0.6 and 2.1 μ . Figure 15 shows the absorptions produced by the various bands over the regions indicated by the lines at the bottom of figure 14, and table 9 shows the losses which the incoming solar energy suffers from these absorptions and from scattering in the atmosphere before reaching sea-level. In table 10 will be found the transmission coefficients, $a_{w\lambda}$ for 1 cm. ppt. H_2O and for zenith passage of solar energy to sea-level ($a_{a\lambda}$) for use in the formula, $e_{\lambda} = e_{0\lambda} \{ a_{a\lambda} a_{w\lambda} \}^m$ for computing the additional losses due to molecular scattering. In this formula w is the ppt. H_2O in cm., m the air mass, in terms of the path vertically through

the atmosphere at sea-level taken as unity. Figure 15 gives means to compute the losses due to absorption in the bands. The scattering losses should be computed first, and then allowance made for the

TABLE 9.—WASHINGTON. ATMOSPHERIC ABSORPTION FOR DRY AIR AND DRY AIR PLUS DUST AND VARIOUS AMOUNTS OF WATER VAPOR

Altitude sea-level; Barometer 76.0 cm.

Incident solar radiation, 1.93 15° C.-gram-calories per sq. cm. per minute

Air masses	m=1		m=2		m=3		m=4		m=5		m=7	
Precipitable water vapor	Gram-Cal. lost	Percentage lost	Gram-Cal. lost	Percentage lost.	Gram-Cal. lost.	Percentage lost	Gram-Cal. lost	Percentage lost	Gram-Cal. lost	Percentage lost	Gram-Cal. lost	Percentage lost
0.00 cm.												
Air scattered.....	0.18	9.3	0.33	17.1	0.44	22.8	0.53	27.5	0.61	31.6	0.73	37.8
Air absorbed.....	.01	0.5	.01	0.5	.01	0.5	.01	0.5	.01	0.5	.01	0.5
Total lost.....	.19	10.0	.34	18.0	.45	23.0	.54	28.0	.62	32.0	.74	38.0
0.5 cm. February 15												
H ₂ O scattered.....	.08	4.1	.15	7.8	.21	10.9	.26	13.5	.30	15.5	.37	19.2
H ₂ O absorbed.....	.12	6.2	.13	6.7	.14	7.3	.14	7.3	.14	7.3	.14	7.3
Total lost.....	.39	20.0	.62	32.0	.80	42.0	.94	49.0	1.06	55.0	1.25	65.0
1.8 cm. October 4												
H ₂ O scattered.....	.26	13.5	.42	21.8	.53	27.5	.61	31.6	.67	34.7	.74	38.3
H ₂ O absorbed.....	.15	7.8	.16	8.3	.16	8.3	.14	7.3	.13	6.7	.11	5.7
Total.....	.60	31.0	.92	48.0	1.14	59.0	1.29	67.0	1.42	74.0	1.59	82.0
2.4 cm. May 14												
H ₂ O scattered.....	.38	19.7	.56	29.0	.67	34.7	.74	38.3	.78	40.4	.83	43.0
H ₂ O absorbed.....	.16	8.3	.16	8.3	.15	7.8	.14	7.3	.13	6.7	.10	5.2
Total.....	0.73	38.0	1.06	55.0	1.27	66.0	1.42	74.0	1.53	79.0	1.67	86.0

TABLE 10.—60° ULTRA-VIOLET GLASS PRISMATIC SOLAR ENERGY-CURVE:
ALSO DRY AIR AND AQUEOUS VAPOR (1 CM. PRECIPITABLE
WATER) TRANSMISSION COEFFICIENTS

λ	0.342	0.350	0.360	0.371	0.384	0.397	0.413	0.431	0.452	0.475
$c_{o\lambda}$	102	130	160	198	227	322	437	518	681	807
$a_{a\lambda}$	(0.595)	(0.626)	0.655	0.686	0.713	0.752	0.783	0.808	0.840	0.863
$a_{w\lambda}$	0.920	0.926	0.934	0.940	0.945	0.949	0.953	0.957	0.961	0.964
λ	0.503	0.535	0.574	0.624	0.686	0.764	0.864	0.987	1.146	1.302
$c_{o\lambda}$	907	1044	1197	1334	1416	1435	1431	1306	1025	775
$a_{a\lambda}$	0.885	0.898	0.905	0.929	0.959	0.979	0.987	0.992	0.996	0.997
$a_{w\lambda}$	0.968	0.972	0.970	0.975	0.981	0.984	0.986	0.987	0.987	0.987
λ	1.452	1.603	1.738	1.870	2.000	2.123	2.242	2.348	.....	.....
$c_{o\lambda}$	586	435	343	262	187	123	88	74	.....	.....
$a_{a\lambda}$	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	.....	.....
$a_{w\lambda}$	0.987	0.987	0.987	0.987	0.986	0.985	0.984	0.983	.....	.....

band absorption losses by means of figure 14, remembering that the losses there given pertain to the energy over a range of wave-lengths indicated by the corresponding lines at the bottom of figure 14.

B. ABSORPTION IN WATER VAPOR AND CARBON DIOXIDE FOR WAVE-LENGTHS 1.2 TO 9.0 μ

(1) LABORATORY CONDITIONS APPROACHING ATMOSPHERIC CONDITIONS AS TO TEMPERATURE, TOTAL AND PARTIAL PRESSURES

Observations described in the main body of this report were made in a 60°-prismatic rock-salt spectrum, of the effect of water vapor and carbonic-acid gas to deplete energy from the radiation of a Nernst lamp (at 2,200° K.) in this spectrum region. The absorbents comprised in some experiments 0.008 cm. ppt. H₂O and carbon dioxide of such an amount that there would have been 7.4 grams in a column the length of the path and a meter square in section; and in other experiments 0.082 cm. ppt. H₂O and 83 grams of carbon dioxide. For mental comparison, the total amount of carbon dioxide similarly measured vertically from the surface of the earth outwards is about 3,000 grams.

The appearance of the absorption bands in the energy curve of the lamp is shown in the lower half of figure 6. The computed percentage absorptions are given in figure 7. The percentage absorptions in regions extending over various wave-length ranges are given in table 4. Paschen's results for carbon dioxide are given in table 3. It is through table 4 that the results are most easily applicable. The amount of radiation available before absorption between the wave-lengths indicated in column 2 should be multiplied by the ratio belonging to the proper amount of ppt. H₂O taken from the columns headed "percentage absorbed" and the result will be the amount lost in the corresponding water vapor. Table 4 may be supplemented for greater amounts of vapor by the data in table 6 obtained from the observations with the 15° rock-salt prism.

(2) RESULTS FOR STEAM (1.2 TO 9.0 μ)

The results obtained by Paschen for steam are given in the *Annalen der Physik und Chemie*, 52, p. 209, 1894. In figure 7 are shown the results for the water-vapor absorption band from 5 to 8 μ . With equal quantities of ppt. H₂O, water vapor in the form of steam evidently produces considerably more absorption than when dispersed at small partial pressure as in the atmosphere, even although the same total pressure prevails. Referring to figure 7 the partial pressure of Paschen's steam (at 100° C.) was equal to its total pressure, 76 cm. The partial pressure of water vapor in the present research (at 20 to 30° C.) was of the order of a centimeter, the total pressure 76 cm.

C. ABSORPTION IN WATER VAPOR FOR WAVE-LENGTHS $9.0\ \mu$ TO $14\ \mu$
AND BEYOND

(1) LABORATORY CONDITIONS APPROXIMATING ATMOSPHERIC CONDITIONS AS TO
TEMPERATURE, TOTAL AND PARTIAL PRESSURES

In the main body of this report will be found in detail the observations for this region made with a 15° rock-salt prism. The amounts of vapor range from 0.003 cm. to 0.26 cm. ppt. H_2O . Figure 8 shows the appearance of a record of bolographic observation, somewhat complicated by the observations necessary to eliminate field light. The principal results relating to the absorption of water vapor are shown in figure 10 and table 7.

For information on the effect of carbon dioxide in this spectrum region (partially indicated by the shaded region in figure 10) the main body of the paper must be consulted. A path through the atmosphere of the order of 100 meters is sufficient to produce complete absorption in the carbon dioxide band between 14 and $15.5\ \mu$ (see fig. 11). Besides the work published by Rubens and Aschkinass, and shown in figure 11, further data will be found in "Über das ultrarote Absorptions-spectrum der Kohlensäure in seiner Abhängigkeit von Druck und Partial-druck," von G. Hertz, Verh. Deutsche Physikalische Gesellschaft, 13, p. 617, 1911.

(2) RESULTS FOR STEAM (7 TO $20\ \mu$)

In figure 11 will be found the results of Rubens and Aschkinass. They show the percentage absorption due to 0.045 cm. ppt. H_2O in the form of steam at 100° C. and 76 cm. pressure. Again by comparison with table 7 it will be noted that the same amount of water in the form of steam gives a greater absorption than when at a smaller partial pressure although the same total pressure.

D. RESULTS FOR STEAM. WAVE-LENGTHS GREATER THAN $20\ \mu$

Isolated results for greater wave-lengths have been obtained by the use of the "Restrahlungen" from various crystals. Rubens and Wartenberg¹ found that a column of steam 40 cm. long 100° C. 76 cm. pressure (0.024 cm. ppt. H_2O), transmits radiation as follows: 39.6 per cent at $23\ \mu$, 0.7 at $52\ \mu$, 19.6 at $110\ \mu$ and 49.2 at $314\ \mu$. At the same wave-lengths 20 cm. of carbon dioxide at 76 cm. pressure showed no absorption. Rubens² later found that water vapor in the whole region between 45 and $120\ \mu$ causes many bands of great

¹ Verh. Deutsche Physikalische Gesellschaft, 13 p. 797, 1911.

² Berichte Kgl. Preuss. Akademie der Wissenschaften, p. 513, 1913.

absorption. It is especially absorbing at $50\ \mu$, $66\ \mu$ and $79\ \mu$ and apparently also at $58\ \mu$ and $103\ \mu$. It is relatively more transparent at $47\ \mu$, $54\ \mu$, $62\ \mu$, $75\ \mu$, $91\ \mu$ and $115\ \mu$.

E. ABSORPTION BY LIQUID WATER

(1) FOR WAVE-LENGTHS LESS THAN $2\ \mu$

It has been thought worth while both for comparison and for its practical value to include the following data for liquid water. As already stated, in giving the absorption of water vapor in terms of the precipitable water, it should not be inferred equivalent to that of the same quantity of liquid water. In general the absorption of an equivalent amount of water is different in the three states, liquid, atmospheric vapor, and steam.

For the shorter wave-lengths data have been obtained by Kreusler,¹ Ewan,² and Aschkinass³ from which are taken the following values of a in the formula $i = i_0 e^{-ad}$ in which d is in cm., i_0 the original intensity of a ray and i its intensity after transmission. A more complete table will be found in Kayser's Handbuch, Vol. 3.

TABLE II.—ABSORPTION OF RADIATION BY LIQUID WATER
WAVE-LENGTHS LESS THAN $0.5\ \mu$

λ in μ	.186	.193	.200	.220	.230	.240	.260	.300	.415	.430	.450	.475	.487	.500
a	.0688	.0165	.0090	.0061	.0057	.0034	.0025	.0015	.00035	.00023	.00020	.00020	.00014	.00020

Between the two absorption bands at $0.115\ \mu$ (metallic absorption⁴) and at $0.50\ \mu$ these values of absorption are what would be expected from purely molecular scattering.⁵ When the same water is in the form of atmospheric vapor its absorption is greater. This will be seen by comparing $a_{w\lambda}$ of table 10, for example at $.5\ \mu$, with the a in the above table at the same wave-length remembering $a_{w\lambda} = e^{-a}$. The vapor value and liquid value in the same units are 0.33 and .0002 respectively.

As the true absorption bands are approached the liquid water rapidly becomes a far more effective absorber than the vapor. The following coefficients, a , are given by Nichols⁶ for the transmission of a cell of water 1 cm. thick.

¹ Annalen der Physik, 6, p. 412, 1901.

² Proceedings of the Royal Society, 57, 117, 1894.

³ Annalen der Physik und Chemie, 55, 401, 1895.

⁴ Martens, Annalen der Physik, 6, p. 603, 1901.

⁵ Astrophysical Journal, 38, p. 392, 1913, and unpublished data.

⁶ Physical Review, 1, p. 1, 1894.

TABLE 12.—TRANSMISSION OF LIQUID WATER (1 CM.) .8 TO 2.8 μ

λ in μ	.779	.865	.945	1.19	1.41 to 2.8
Transmission per cent ..	76.2	74.4	58.4	14.4	Too small to measure

W. Schmidt¹ in his "Absorption der Sonnenstrahlung im Wasser" gives computations based upon the data of Aschkinass shown in figure 16. He gives the transmission for various thicknesses of water and states that a layer 1,000 m. thick produces complete absorption for wave-lengths greater than 0.6 μ , 10 m. for those greater than 0.9 μ , 10 cm. for those greater than 1.2 μ , 1 cm. for those greater than 1.5 μ and 1 mm. for those greater than 2.4 μ . It should be remembered that his results are from computation. Because of the

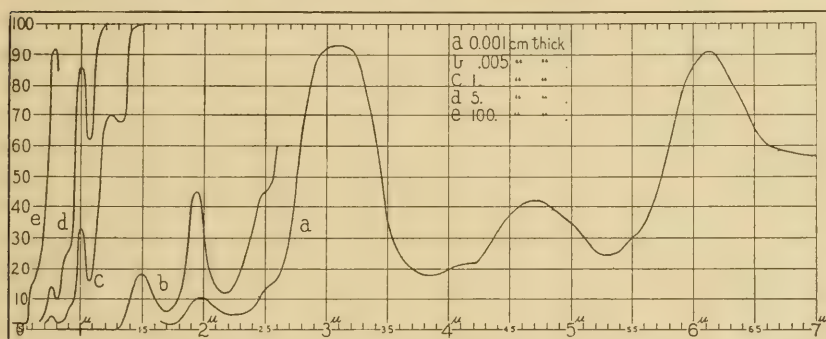


FIG. 16.—Absorption of radiation by liquid water. Aschkinass, *Annalen der Physik und Chemie*, 55, p. 401, 1895. Abscissae are wave-lengths in microns (μ). Ordinates are percentage transmissions.

impurity of the spectrum used to obtain the transmission of vapor, and the banded nature of the absorption, such computations based on Bouguer's formula are doubtful, and inferences obtained from the curves of figure 16 would probably be as satisfactory.

(2) ABSORPTION BY LIQUID WATER, WAVE-LENGTHS 1 μ TO 8 μ

In figure 16 will be found a portion of the data obtained by Aschkinass for layers of water ranging from 0.001 cm. to 100 cm. thick. The curve continues on nearly horizontally from 7 to 8 μ . The data will be found given in much greater detail in the original publication.²

¹ Sitzungberichte K. Akad. der Wissenschaften, 117, 2 A, p. 237, 1908.

² *Annalen der Physik und Chemie*, 55, p. 401, 1895.

(3) ABSORPTION BY LIQUID WATER, WAVE-LENGTHS 1 TO 18 μ

In figure 17 are given data obtained by Rubens and Ladenburg¹ with the use of two bubble films, one (b) 3.09 μ thick and containing 10 per cent glycerine, the other (a) 1.89 μ thick and containing 25 per cent glycerine. The maxima in both curves at 7.0 and 9.5 μ are probably due to glycerine.

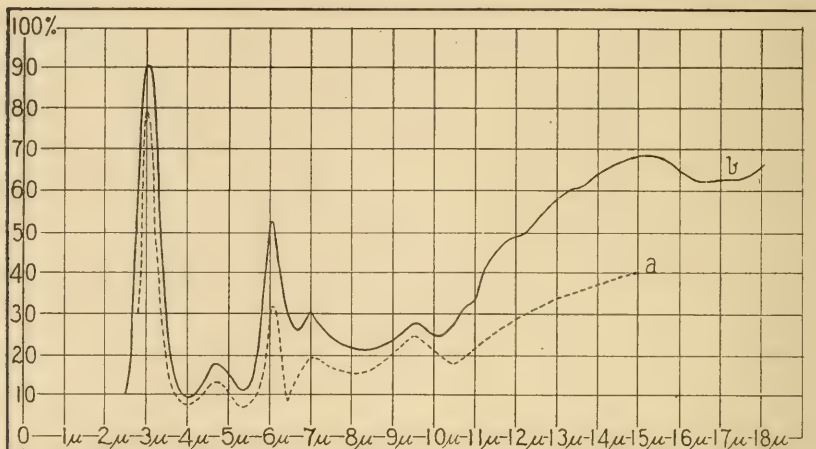


FIG. 17.—Absorption of radiation by liquid water films. Rubens and Ladenburg, *Verh. D. Phys. Gesell.* 11, p. 16, 1909. Abscissae are wave-lengths in microns (μ). Ordinates are percentage absorptions. *a*, film 0.00789 mm. thick; *b*, 0.00309 mm. thick.

The main laboratory results of this research, done to obtain quantitative measures of the transparency of aqueous vapor for radiation, have just been summarized. Below the great water-vapor band 6 to 8.5 μ , which is very strong even with the small amounts of vapor present in the laboratory, the great transparency of the region stretching from 9 towards 14 μ was surprising and absorption effects there were scarcely perceptible. The total depletion of energy by the great carbon dioxide band 14 to 15.5 μ and the decreasing transparency of the rock-salt prism employed prevented results for longer wave-lengths.

F. ATMOSPHERIC TRANSMISSION OF SOLAR ENERGY. 9 TO 15 μ

The unexpected transparency for wave-lengths just longer than 9 μ led to direct observations of solar energy through paths in air which increased with decreasing altitudes of the sun. A range of

¹ *Verh. Deutschen Physikalischen Gesellschaft*, 11, p. 16, 1909.

aqueous vapor from 0.6 cm. to over 3 cm. ppt. H_2O was thus obtained. Except in the band probably due to ozone at about $10.3\ \mu$ no systematic change appeared in this region of spectrum (see fig. 13) and thus great transparency was indicated. This band at $10.3\ \mu$ systematically deepens with increasing air-mass.

G. COLLECTED RESULTS ON ATMOSPHERIC ABSORPTION FOR LONG-WAVE RADIATION

Table 13 contains a summary of the results on the absorptive power of atmospheric water vapor and their application to determine the total radiation outwards vertically to space from the earth when the atmosphere contains 0.003, 0.03, 0.3 and 3.0 cm. precipitable water. The effect of carbon dioxide and the band of unknown origin at about $10\ \mu$ has been included:

TABLE 13.—ATMOSPHERIC ABSORPTION OF EARTH RADIATION

Range of wave-length μ	Energy of black body 287°K.	Percentage absorption			
		Precipitable water in cm.			
		0.003	0.03	0.3	3.0
3-4	5	10	30	50	75
4-5	50	15	45	70	95
5-6	142	16	43	66	95
6-7	242	45	85	95	100
7-8	315	13	42	85	100
8-9	360	0	2	40	50
9-10	380	0	0	0	15
10-11	370	0	2	5	40
11-12	350	0	0	4	10
12-13	320	0	0	13	20
13-16	810	100	100	100	100
16-20	510	(90)	100	100	100
20-30	900	(70?)	(80?)	(90?)	100
30-40	300	(100?)	(100?)	(100?)	100
40-50	150	(100)	(100)	(100)	(100)
50-60	75	(100)	(100)	(100)	(100)
3-60	5,279	49	57	66	75

In accordance with the values given in the last line of the table the vertical transmissions of the earth's radiation are therefore 51, 43, 34, and 25 per cent, corresponding to 0.003, 0.03, 0.3, and 3 cm. ppt. H_2O . Further, applying these last figures to the transmission of radiation outwards in all directions from a horizontal surface at sea-level, assuming Lambert's cosine law, and 1 cm. ppt. H_2O , it is found that 28 per cent of the earth's radiation under such circumstances passes directly out to space.

H. SUBSIDIARY INVESTIGATIONS

(1) CORRECTION FOR SLIT AND BOLOMETER WIDTHS

The different angular widths of the bolometer and the slit necessitated the derivation of a new formula for reducing approximately the observed spectrum intensities to what they would have been with an infinitely narrow slit and bolometer. This derivation with its limitations is given in Appendix I.

(2) FIELD ENERGY DUE TO SCATTERING

The complication arising from the immense amount of scattered light present in a spectrum of such great range of intensities (100,000 fold) and small dispersion required extended study. This discussion covered the energy scattered into any region from all wavelengths as well as that scattered away. It will be found in Appendix II, where a separate summary gives the generalizations.

(3) TRANSPARENCY OF IODINE. FIGURE 12

The need of a suitable absorbing screen to cut out the intense short wave energy, the scattering from which rendered observations otherwise useless in the solar spectrum, led to the preparation of a thin film of iodine, 0.005 to 0.007 cm. thick between two rock salt plates whose combined thickness was about 1 cm. The results of two measures of the transparency of the iodine film are shown in figure 12.

(4) COMPARISON OF NERNST LAMP SPECTRUM WITH THAT OF BLACK BODY

The comparison of the radiation from a black-body radiating at 2,200° K. (apparent black-body temperature of the lamp) to one at 300° K. (the temperature of the shutter used for zero deflection) is shown in figures 6, 9, and 10. The agreement, with due allowance for the absorption bands, seems satisfactory down to about 10 μ . From here on the lamp curve increasingly falls below the black-body curve. It is uncertain that the lamp radiates here as a black-body but the departure may be chiefly due to the decreasing absorption of the incident radiation by the soot-blackened surface of the bolometer.

NOTE

There are two doubtful points upon which light has been thrown since the above was written: 1st, May not even the small amount of aqueous vapor present in the path through the spectroscope exercise nearly complete and considerable absorption in narrow lines

in the region from 9 to 15 μ and yet the additional amounts of vapor produce no further absorption there? 2d, In treating of the earth's radiation outward, complete absorption for atmospheric amounts of vapor has been assumed for wave-lengths greater than 20 μ . Is this certain? The first point could be settled only by observing the radiation through a path containing no water vapor. Dr. Coblenz (Proc. Nat. Acad. Sc. 3, p. 504, 1917) has just published observations on a black body radiating at 800° C. Comparing the radiation after passing through a tube containing 0.00045 cm. ppt. H₂O with that when the tube was exhausted he found the absorption due to this amount of vapor to be about 0.9 per cent. If all the absorption had been produced in the region between 9 and 15 μ , the mean absorption in this region must have been 12 per cent. 12 per cent, then, is the maximum absorption permissible here with this amount of vapor. Assuming the absorption in the known water-vapor bands is proportional to the amount of vapor, within the range from no vapor to the smallest amount used in the present research, the following table is probably representative of the absorptions from wave-length to wave-length in Dr. Coblenz' case.

Wave-lengths (μ)	1.5-2.0	2-3	3-4	4-5	5-6	6-7	7-8	8-9
Percentage absorption..	0.5	1.0	1.0	1.0	2.0	5.0	1.5	0
Relative energy black body, 800°C.....	300	1380	1400	1030	750	550	400	270

Total energy same scale, 6825.

The absorption computed from the above data would be 1.3 per cent, which is probably within experimental error the same as that found by Dr. Coblenz. This confirms the conclusion of great transparency in the region between 9 and 15 μ .

As to the second point, recent nocturnal experiments by Mr. L. B. Aldrich on Mount Wilson with the pyranometer, employing salt and sylvine screens tend to confirm the assumption that the atmosphere transmits no appreciable quantity of radiation from the earth of wave-lengths greater than 20 μ .

APPENDIX I

CORRECTION TO OBSERVED ENERGY CURVE FOR WIDTH OF SLIT AND BOLOMETER

The true monochromatic intensity in a spectrum would occur only with the use of an infinitely narrow slit and then the intensity would be infinitely small. As both the slit and the observing device must

be of finite width, an intensity is observed which corresponds to the sum of the intensities of the energy of the various wave-lengths falling on the observing device, a bolometer in the present case. A correction must be determined for reducing the observed intensity to the pure or monochromatic value. Such a correction for the case where both the slit and the observing apparatus subtend the same angular value in the spectrum has been determined by Runge.¹ His method of deriving the correction is not directly applicable to the present case where the widths may be unequal and the following modification in the derivation was suggested by Dr. Abbot and worked out in cooperation with the writer in 1909. The resulting equation was applied to all the observed energy curves of the present research.

Let x denote the position (deviation) in the spectrum under consideration. At x , then, lies the middle of the slit image of the color whose wave-length may be λ . This slit image will extend from the deviation $x - \frac{a}{2}$ to $x + \frac{a}{2}$ where a is the slit width expressed as its angular value in the spectrum. It is assumed here, with safety, that the spectrum on each side of x is a minimum deviation spectrum, although this is not strictly true. Each wave-length as it falls in succession from the center of the slit upon the center of the bolometer is kept automatically in minimum deviation but the image of the whole spectrum formed at any time at the bolometer is not strictly a minimum deviation spectrum.

The amount of energy, which should appear in the deviation from x to $x+dx$, is not condensed in the interval dx but spread over the interval from $x - \frac{a}{2}$ to $x + \frac{a}{2}$. Let the amount of this energy be adE_x where dE_x is the amount of energy flowing through unit slit in unit time. Of this energy only the portion $dE_x \cdot dx$ falls in the interval between x and $x+dx$. However portions of the slit images belonging to the deviations $x - \frac{a}{2}$ to $x + \frac{a}{2}$ to each side, do fall within the interval dx so that the total amount of energy falling in the interval between x and $x+dx$ is equal to

$$dx \int_{-\frac{a}{2}}^{+\frac{a}{2}} \frac{dE_{x+v}}{dv} dv = \left\{ E \left(x + \frac{a}{2} \right) - E \left(x - \frac{a}{2} \right) \right\} dx.$$

¹ "Ueber die Differentiation Empirischen Functione," *Zeitschrift für Mathematik und Physik*, 42, 1897; see also Hyde, *Astrophysical Journal*, 35, p. 237, 1912.

The intensity of the spectrum at x may be defined as the energy over an indefinitely small interval dx divided by dx . That of the impure spectrum at x is therefore

$$\left\{ E\left(x + \frac{a}{2}\right) - E\left(x - \frac{a}{2}\right) \right\}.$$

That of the pure spectrum is $\frac{dE_x}{dx} \cdot a$ as a becomes infinitely small.

However, only the relative intensity from one part of the spectrum to another is required and not necessarily the absolute infinitely small intensity which the abstract pure spectrum would have.

In measures with the bolometer not even the intensities in this impure spectrum are obtained directly but rather the sum of the intensities in it over the region covered by the bolometer. If the middle of the bolometer is at the deviation x and its width is b , then it receives in a unit time the amount of energy

$$F(x) = \int_{-\frac{b}{2}}^{+\frac{b}{2}} \left\{ E\left(x + v + \frac{a}{2}\right) - E\left(x + v - \frac{a}{2}\right) \right\} dv.$$

The observed intensity in the spectrum is proportional to this $F(x)$.

A development of $\frac{dE_x}{dx}$, which is proportional to the intensity in the pure spectrum, in terms of $F(x)$ is desired.

If $f(x)$ is taken to denote $\frac{dE}{dx}$, then by Taylor's theorem

$$E\left(x + v + \frac{a}{2}\right) = E(x) + f(x)\left(v + \frac{a}{2}\right) + \frac{1}{2!}f'(x)\left(v + \frac{a}{2}\right)^2 + \dots$$

so that

$$\int_{-\frac{b}{2}}^{+\frac{b}{2}} E\left(x + v + \frac{a}{2}\right) dv = E(x)b + f(x)\frac{ab}{2!} + f'(x)\frac{3a^2b + b^3}{3!4} + \dots$$

Making a similar development for the second term of the expression for $F(x)$ and subtracting, there results

$$F(x) = 2\left\{ f(x)\frac{ab}{2!} + f''(x)\frac{a^3b + ab^3}{4!2} + \dots \right\}$$

Let $b = an$, a being the slit width and n the ratio of the width of the bolometer to that of the slit, then

$$F(x) = 2\left\{ \frac{na^2}{2!}f(x) + \frac{na^4(1+n^2)}{4!2}f''(x) + \frac{na^6(3+10n^2+3n^4)}{6!4^2}f^{iv}(x) + \dots \right\}.$$

Similar developments may be made for $F''(x)$, $F^{iv}(x)$, , whence using the undetermined coefficients C_1 , C_2 , as multipliers and adding:

$$F(x) + C_1 F''(x) + C_2 F^{iv}(x) + \dots = 2 \left\{ \frac{na^2}{2!} f(x) + \left[\frac{na^4(1+n^2)}{4!2} + \frac{na^2}{2} C_1 \right] f''(x) + \left[\frac{na^6(3+10n^2+3n^4)}{6!4^2} + \frac{na^4(1+n^2)}{4!2} C_1 + \frac{na^2}{2} C_2 \right] f^{iv}(x) + \dots \right\}.$$

Putting $k_1 = n$, $k_2 = n(1+n^2)$, $k_3 = n(3+10n^2+3n^4)$, and equating coefficients, it follows then that

$$a^2 k_1 f(x) = F(x) - \frac{k_2 a^2}{k_1 24} F''(x) + \frac{10k_2^2 - k_2 k_1}{k_1^2} \frac{a^4}{5760} F^{iv}(x) \dots \quad (1)$$

Now letting $2ca$ be the portion of the energy curve covered by the slit plus the bolometer, c being equal to $1+n$ and therefore $2ca$ to $2(a+b)$, then

$$F(x+ca) = F(x) + ca F'(x) + \frac{c^2 a^2}{2!} F''(x) + \frac{c^3 a^3}{3!} F^{iii}(x) + \frac{c^4 a^4}{4!} F^{iv}(x) + \dots$$

Forming a similar development for $F(x-ca)$ and adding and transposing, there follows

$$F''(x) = \frac{2}{c^2 a^2} \left\{ \frac{F(x+ca) + F(x-ca)}{2} - F(x) - \frac{c^4 a^4}{4!} F^{iv}(x) + \dots \right\}$$

which may be put in the form

$$F''(x) = \frac{2}{c^2 a^2} \left\{ \phi_1(x) - \frac{c^4 a^4}{4!} F^{iv}(x) + \dots \right\}$$

Substituting in (1) there follows that

$$a^2 k_1 f(x) = F(x) - \frac{k_2}{k_1} \frac{1}{12c^2} \phi_1(x) + \frac{10k_2^2 - k_2 k_1 + 20k_2 k_1 c^2}{5760 k_1^2} a^4 F^{iv}(x) + \dots \quad (2)$$

Now

$$\phi_1(x) = \left\{ \frac{F(x+ca) + F(x-ca)}{2} - F(x) \right\},$$

and

$$\phi_1(x+ca) = \phi_1(x) + ca \phi_1'(x) + \frac{c^2 a^2}{2!} \phi_1''(x) + \frac{c^3 a^3}{3!} \phi_1^{iii}(x) + \dots$$

making a similar development for $\phi_1(x-ca)$, adding and transposing

$$\phi_1''(x) = \frac{2}{c^2 a^2} \left\{ \frac{\phi_1(x+ca) + \phi_1(x-ca)}{2} - \phi_1(x) \right\} + \dots$$

which let equal, say, $\frac{2}{c^2 a^2} \phi_2(x)$; but

$$\phi_1(x) = \frac{c^2 a^2}{2} F''(x) + \dots$$

$$\phi_1''(x) = \frac{c^2 a^2}{2} F^{iv}(x) + \dots$$

Whence

$$\begin{aligned} F^{iv}(x) &= \frac{2}{c^2 a^2} \phi_1''(x), \text{ approximately} \\ &= \frac{4}{c^4 a^4} \left\{ \frac{\phi_1(x+ca) + \phi_1(x-ca)}{2} - \phi_1(x) \right\} \\ &= \text{say, } \frac{4}{c^4 a^4} \phi_2(x). \end{aligned}$$

Substituting in (2) there results the following development of the energy curve $f(x)$ as, with certain reservations, it might be expected to appear with an infinitely narrow slit and bolometer, in terms of the observed energy curve $F(x)$.

$$\begin{aligned} a^2 k_1 f(x) &= F(x) - \frac{k_2}{k_1} \frac{1}{12c^2} \phi_1(x) \\ &\quad + \frac{10k_2^2 - k_3 k_1 + 20k_1 k_2 c^2}{1440k_1^2 c^4} \phi_2(x) + \dots \\ &= F(x) - \frac{1+n^2}{12c^2} \phi_1(x) + \frac{7+10n^2+7n^4+20c^2(1+n^2)}{1440c^4} \phi_2(x) + \dots \end{aligned}$$

When $n=1$, or the slit and the bolometer are of the same angular width in the spectrum, which is Runge's case, the second half of the above equation reduces to

$$= F(x) - \frac{1}{6} \phi_1(x) + \frac{2}{45} \phi_2(x) + \dots$$

The coefficients for the various cases in the present research were:

TABLE 14.

Slit mm.	a^* mm.	Bolometer mm.	b^* mm.	Coefficients of		$\frac{2ca}{2a(1+n)}$
				ϕ	ϕ_2	
0.67	0.05	0.5	0.29	$\frac{1}{4}$	0.086	0.68
2.40	.19	....	....	$\frac{1}{6}$	.047	0.96
4.99	.40	....	....	$\frac{1}{6}$	.046	1.38
5.82	.46	....	....	$\frac{1}{6}$	.049	1.50
10.69	.85	....	....	$\frac{1}{3}$	.063	2.28

* Equivalent to differences of deviation as expressed in millimeters on the bolographs or energy curves.

An example will best show the method of using the formula. Taking the case with a slit of 0.67 mm. linear width and subtending in the spectrum an angular width equivalent to 0.05 mm. as measured on the plate (equal to a) and a bolometer 0.5 mm. wide and subtending 0.29 mm. (equal to b) on the plate, then the formula becomes

$$a^2k_1f(x) = F(x) - 1/4 \cdot \phi_1(x) + 0.086\phi_2(x)$$

$$= F(x) - \frac{1}{4} \left\{ \frac{F(x+3mm) - F(x-3mm)}{2} - F(x) \right\}$$

$$+ 0.086 \left\{ \frac{\phi_1(x+3mm) - \phi_1(x-3mm)}{2} - \phi_1(x) \right\} \dots$$

TABLE 15.—EXAMPLE OF THE APPLICATION OF THE FORMULA FOR CORRECTING FOR THE FINITE WIDTH OF THE SLIT AND THE BOLOMETER

x	$F(x)$	$\phi_1(x)$	$\phi_2(x)$	$-\frac{1}{4}\phi_1(x)$	$+0.086\phi_2(x)$	$a^2k_1f(x)$
0	1,000	....	....	....	....	....
1	1,120	....	....	....	....	....
2	1,220	....	....	....	....	....
3	1,300	-103	....	+26	....	....
4	1,360	-105	....	+26	....	....
5	1,390	-105	....	+26	....	....
6	1,395	-100	-10	+25	-1	1,419
7	1,390	-105	-3	+26	0	1,416
8	1,350	-100	+5	+25	0	1,375
9	1,290	-118	+66	+29	+6	1,325
10	1,210	-110	+81	+28	+7	1,245
11	1,110	-85	+70	+21	+6	1,137
12	950	-5	-24	+1	-2	949
13	810	+46	-70	-11	-6	793
14	700	+70	-84	-18	-7	675
15	600	+60	-38	-15	-3	582
16	503	+62	-21	-15	-2	486
17	430	+56	....	-14	....	....
18	370	+50	....	-12	....	....
19	320	+36	....	-9	....	....
20	272	....	....	....	..	....
21	241	....	....	....	....	....
22	210	....	....	....	....	....

The first step as followed out in table 15 was to read $F(x)$, the observed energy curve at every mm. Next $\phi_1(x)$ was obtained by subtracting, for example, the value of $F(x)$ at $x=3$ from the mean of the values at $x=3-3$ or 0 and $x=3+3$ or 6 and so on proceeding down the column. $\phi_2(x)$ was obtained from $\phi_1(x)$ exactly as was $\phi_1(x)$ from $F(x)$. The completion of the process is evident from the headings of the columns, the final column giving the corrected energy curve.

LIMITATIONS

It is evidently impossible by any such process as that just developed and described to obtain, in general, from an impure spectrum, a pure spectrum, except in the case of a continuous energy curve such, for instance, as would be expected from an incandescent black body. A line cannot be made to appear which has been completely obliterated by the impurity of the spectrum although one which has been rendered shallow may be deepened, and a maximum which has been lowered may be made to approximate its proper height.

APPENDIX II

STRAY LIGHT AND ITS DETERMINATION

The most intense region in the rock-salt prismatic spectrum of the Nernst glower lies at wave-lengths less than $4\ \mu$. From this region, which is transmissible by quartz, most of the field light comes. At $4\ \mu$ the intensity of the spectrum had already decreased nearly to 1/10. Interest in the present research centers in wave-lengths greater than $4\ \mu$ and *not* transmissible by quartz. Energy proper to any place in the spectrum of wave-length greater than $4\ \mu$ has been distinguished from that scattered into it from the intense short-wave-length spectrum region by observing what portion of the deflection remains when a plate of quartz is inserted between the source of energy and the spectroscope slit. Since the quartz is opaque to radiation of wave-lengths greater than $4\ \mu$, the deflection observed through quartz must be all false and due to energy of wave-length less than $4\ \mu$. Without the quartz, the deflection represents this false energy, plus the true longer-wave radiation, plus certain other corrections to be presently considered.

Turning again to figure 8, the significance of the central curve $a'b'c'd'e'$ as a means of determining this field light will be considered. This curve, which is essentially an energy curve of the source observed through a plane parallel quartz plate $1/2$ cm. thick, consists of two parts of quite different significance, namely, region a and region $b'c'd'e'$.

Region a' .—Curve a' indicates approximately the intensity of energy in the lamp spectrum for wave-lengths between 0.6 and $4.0\ \mu$ for which quartz is nearly transparent. The difference between the areas a and a' (after making certain correction for the absorption in the quartz of the longer waves between 3 and $4\ \mu$) measures the amount of energy of this region reflected from the quartz surfaces.

This amount can also be computed by Fresnel's and by Bouguer's formulae for reflection and absorption, respectively, from the known coefficients of refraction (Rubens)¹ and transmission (Merritt).² Several computations made before the idea of inserting the quartz in this branch had occurred, gave this loss as about 19 per cent. Considering the uncertainties due to the great impurity of the spectrum used for computing this loss, this is in sufficient agreement with the mean value of 15 per cent found from subsequent curves like *a* and *a'*.

Region b'c'd'e'.—For the energy of prismatic deviations belonging to the region *b'c'd'e'* quartz is opaque. The energy recorded must therefore belong to wave-lengths for which quartz is transparent. That is to say, the observed energy is scattered from and belongs to region *a*. There must be reflected from the quartz surfaces some of the energy scattered into the second region (namely, an amount corresponding to the difference in energy between the areas *a* and *a'*). Therefore the curve *b'c'd'e'* does not represent all the energy scattered here from *a'* but requires to be increased by the mean observed ratio *a/a'* (or 1.18) in order to represent the total field light from region *a'*.³ But even this is not sufficient to give the total field light in the long-wave parts of the spectrum for it gives only that coming from region *a* and it will be directly seen that the scattered energy of even longer wave-lengths than $4\ \mu$ is appreciable. The somewhat complex determination of the correction for stray light, not transmissible by quartz, will now be considered.

The two regions *a* and *b'c'd'e'* corrected as just described and reduced to a more convenient scale are reproduced in figure 18 as *a* and *b₁'c₁'*, the latter magnified respectively a thousand fold and three thousand fold relative to region *a*. With close approximation the first curve may be considered as the energy curve of the region producing the scattering shown in the second. The energy curve of the region *a*, from which the energy is scattered, seems so symmetrical that it appears probable that the distribution of scattered energy from it, *b₁'c₁'*, would not be materially altered if all its energy should be concentrated at the center of the region. Let it be assumed that the whole energy of region *a* is concentrated in a central strip 4' of spectrum (1 cm. of plate) wide as indicated by the dotted lines in figure 18. Let this central strip be joined to the curve *b₁'c₁'* by

¹ Rubens, *Annalen der Physik und Chemie*, 54, p. 476, 1895.

² Merritt, *Annalen der Physik und Chemie*, 55, p. 459, 1895.

³ As stated above the mean loss observed is 15 per cent. The reciprocal of the 85 per cent remaining is 1.18.

what seems a plausible interpolation. Then this central strip, with its wing-like appendage $b_1'c_1'$, may be assumed to represent the energy curve of an approximately monochromatic source of radiation, including the portion of its energy scattered through the spectrum region on its long wave-length side. A symmetrical wing should evidently stretch to its short wave-length side also.

It is proposed to use the curve just described to obtain the scattering taking place at each point in the spectrum from wave-lengths

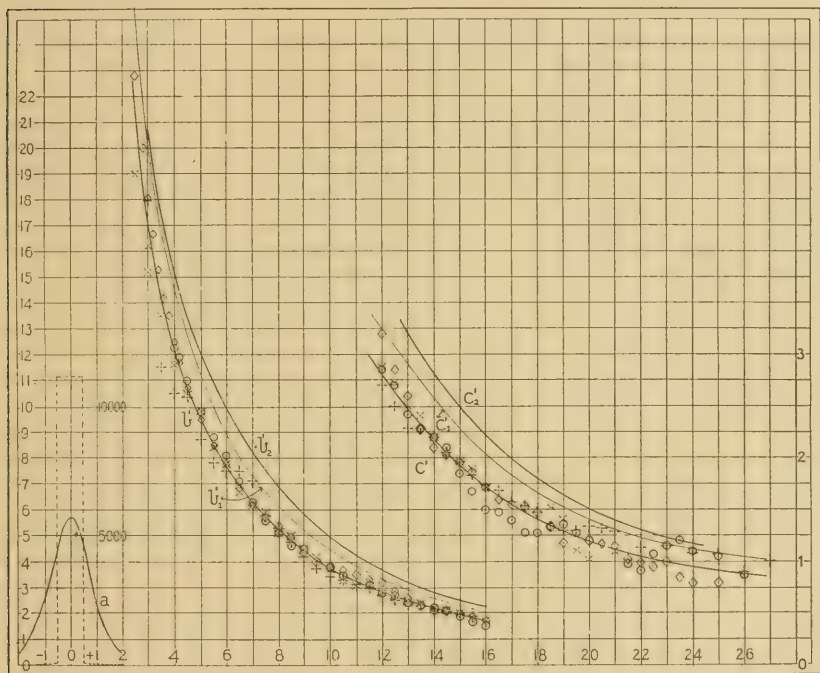


FIG. 18.—Field-light curves.

greater than 4μ and not directly obtained by the insertion of the quartz plate. This involves the assumption that the contour of this curve representing the scattering is the same for all wave-lengths coming into consideration. Gorton¹ has published curves showing, for great angles of incidence and unpolished, comparatively rough surfaces, the variation of the scattering with the wave-length. These show, as might be expected, less scattering for the longer wave-lengths. The smallest angle of incidence used was 54° . The obser-

¹ Physical Review, 7, p. 74, 1916.

vations indicate, as the angle of incidence decreases, a much more uniform reflective power for different wave-lengths, even with such rough surfaces. Accordingly the assumption of a comparatively uniform scattering power at nearly normal incidence (about 3° in the present case) for polished surfaces is not unreasonable.

In order to compute the relative amount of true and scattered radiation at any prismatic deviation an analytical expression for the observed spectrum in terms of these quantities will be built up and then modified to suit actual computations. The first term of this equation should represent, for any deviation, the energy due to the ordinary dispersion of the prism, the second term that lost from the region by scattering and the third that gained by scattering.

Let θ be the deviation taken as zero at 1.8μ . Let $S(\theta)$ represent the function which is the analytical expression of the complete, symmetrical curve of scattering of approximately monochromatic light, the central and right-hand portion of which curve is shown as $a_1'b_1'c_1'$ in figure 18. Let the true energy curve of the lamp be $E(\theta)$, and the observed energy curve $E_0(\theta)$.

The first term of the equation for $E_0(\theta)$ is evidently $E(\theta)$, the energy proper to the deviation.

The second term represents the energy properly belonging to this deviation, but scattered elsewhere. To a close degree of approximation, it is equal to the area of the curve of scattering taken so that its maximum ordinate is equal to the true intensity in the spectrum. With the reservation stated in the second succeeding paragraph, which also applies to the third term, it is therefore equal to $\int_{-\infty}^{+\infty} S(x)dx$ multiplied by the ratio of the ordinate of the true energy curve, $E(\theta)$, at this deviation to that at 1.8μ , $E(\theta_0)$, where θ_0 is taken to signify $\theta=0$.

The third term represents the energy belonging to other deviations but scattered here. To a close degree of approximation it is equal to a sum of successive infinitesimal areas determined by $S(\theta)$, the distance of each area, infinitely narrow in abscissae, from the maximum of $S(\theta)$ being determined by the distance $(\theta+x)$ of the deviation contributing the scattering. The height of the area is so taken that the height of the corresponding maximum, $S(\theta_0)$, shall be equal to the true height of the energy curve at the deviation from which this scattered portion is derived. Analytically this is equal to $S(x)dx$ multiplied by the ratio of $E(\theta+x)$ to $E(\theta_0)$ and integrated over all deviations.

The integrals of the second and third terms will be seen to both contain the term $S(x) \frac{E(\theta)}{E(\theta_0)} dx$ which is not desired but which fortunately occurs in the two integrals with opposite sign. In other words, the function used for the scattered energy includes the energy which should be observed at $\theta=0$ and which is not to be considered as scattered energy. This energy is accounted for in $E(\theta)$.

Accordingly the following expression is obtained:

$$E_0(\theta) = E(\theta) - \frac{E(\theta)}{E(\theta_0)} \int_{-\infty}^{\infty} S(x) dx + \frac{1}{E(\theta_0)} \int_{-\infty}^{\infty} E(\theta+x) S(x) dx,$$

or transposing,

$$E(\theta) = E_0(\theta) + \frac{E(\theta)}{E(\theta_0)} \int_{-\infty}^{\infty} S(x) dx - \frac{1}{E(\theta_0)} \int_{-\infty}^{\infty} E(\theta+x) S(x) dx.$$

All the functions on the right-hand side of the second equation are known except $E(\theta)$. For this may be substituted a first approximation to it obtained by subtracting from the observed lamp deflections the amount of scattered energy indicated by the quartz plate, suitably corrected, as already described, for the reflections from the surface of the plate. The resulting values, which call $E_a(\theta)$ will be found at their greatest to differ by only about 1 per cent where they are of importance in deriving the additional scattered energy. Hence $E_a(\theta)$ will be a sufficiently close approximation for use in the second and third terms.

Table 16 shows the process used to evaluate this expression for the total field light. The numbers in the first column and the first line indicate the prismatic deviations (θ) measured in centimeters on the plate (1 cm.=4' of deviation in the spectrum, zero of deviation at 1.8 μ). Each other number is a measure of the energy under the curve $S(\theta)$ summed for a difference of deviation extending from -0.5 to +0.5 from the indicated deviation. It represents that portion of energy scattered from the deviation at the top of the column into that indicated in the first column.

$$E_a(\theta)$$

Consider first the numbers surrounded by the rectangles and appearing like a flight of steps. These represent $E_a(\theta)$, the first approximation to the true amount of energy in the spectrum of the lamp for the corresponding deviations indicated in the first line or column. They represent also the terms common to both integrals.

$$\frac{E(\theta)}{E(\theta_0)} \int_{-\infty}^{+\infty} S(x) dx$$

this deviation plus that scattered to other deviations. The sum, excluding the "step" value and therefore equal to the amount scattered and lost from the corresponding wave-length, is expressed at the foot of the column of zero deviation. It amounts to about 3 per cent of the intensity observed at the deviation to which the energy belongs. This correction of 3 per cent, in accordance with one of the assumptions, is independent of the wave-length and therefore does not alter the shape of the energy curve.

$$\frac{1}{E(\theta_0)} \int_{-\infty}^{+\infty} E(\theta+x)S(x)dx$$

Consider next the horizontal lines. The numbers added in this direction, including the "step" value, give the values of the term containing the second integral. When added, excluding the "step" value, they give the amount of light scattered into the region indicated by the "step" value of the line from the regions whose deviations are indicated at the tops of the columns of the individual terms of the sum. Remembering that the first-integral term does not affect the shape of the desired energy curve since it may be put in the form of a constant factor multiplying the observed energy of each deviation, the values connected with the second integral are those in which interest will at present center.

In the set of sums in the right-hand group of columns, will be found in the first column the sums taken horizontally from the 2d to the 8th columns inclusive. These values give the energy scattered from the wave-lengths between the deviations -4 and $+2$ cm. (*i. e.*, wave-lengths transmissible by quartz) into the corresponding deviations of the horizontal lines. These values therefore should be, and are, proportional to the field energy obtained by the insertion of the quartz plate. The next column gives the sums of the numbers taken horizontally completely across, but omitting the "step" values. They represent the total field energy due to scattering from all wave-lengths. The next column gives the division of the second of these sums by the first, or is the ratio by which the total field light exceeds that contributed from the region for which quartz is transparent. The last column includes the factor 1.18 to correct for the reflection from the quartz surfaces.

It is evident then from inspection of the last two columns that the deflection obtained on the insertion of quartz has to be increased not only by 18 per cent for losses by reflection from the quartz surfaces but also by an added amount of from 2 to 11 per cent in order to obtain the total energy scattered from all spectrum regions into that

under observation. The total field light therefore ranges (last column) from 20 to 30 per cent greater than that observed with the quartz plate. This added amount depends on the shape of the energy curve. It is somewhat less the greater the amount of water vapor because of the considerable absorption by the water vapor of the energy less than $9\ \mu$ which plays such a disturbing rôle in the production of field energy.

SUMMARY

The following table gives a summary indicating the amounts and increasing importance of the scattered light with increasing angular deviation. This increasing importance with increasing prismatic deviation depends on the more rapid decrease of the energy in the prismatic spectrum than in the scattered band of energy overlapping this spectrum.

TABLE 17.—FIELD LIGHT SUMMARY

1 Wave-length in (μ)	1.8	5.0	5.7	7.0	8.0	10.0	12.0	14.0	17.5
2 Deviation in (')	0	8	10	15	20	30	45	60	100
3 Deviation in (cm.)	0	2.0	2.5	3.8	5.0	7.5	11.2	15.0	25.0
4 Quartz transmits	85,000	504	206	117	85	50	27	17	8
5 $1.18 \times$ ditto	100,000	595	242	141	100	59	30	20	10
6 Total field light		600	244	146	107	66	33	22	11
7 Black-body radiation	100,000	8,000	5,000	1,800	1,000	400	140	65	20
8 Nernst lamp	100,000	8,000	5,000	1,800	1,000	400	140	50	2

Line 1 gives the wave-lengths in millionths of a meter (μ).

Line 2 gives the difference of deviation in minutes of arc (') in a 15° rock-salt prismatic spectrum, the deviation at $1.8\ \mu$ being taken as zero.

Line 3 gives these differences as cm. measured on the plate $1\ \text{cm.} = 4'$.

Line 4 gives the Nernst-lamp spectrum observed through a quartz plate, $\frac{1}{2}$ cm. thick. The energy indicated belongs to the deviation but not to the wave-lengths indicated as it must be all of wave-lengths transmissible by quartz, namely, less than $4\ \mu$.

Line 5 is 1.18 times line 4, allowing for reflection of energy of wave-length less than $4\ \mu$ from the quartz surfaces. It nearly represents the energy curve of a monochromatic line of intensity 100,000 together with the energy scattered to the long wave-length side. See curve ab_1c_1' of figure 18 for a representation of this energy curve.

Line 6 is line 5 increased by the process developed in this appendix to give the total light scattered from all wave-lengths as it would occur in the spectrum of a Nernst lamp when the intensity of the latter is taken as 100,000 at $1.8\ \mu$ (see line 8). These values are represented by the curves b_2c_2' of figure 18.

Line 7 computed relative intensities in the black-body spectrum of a source at $2,200^\circ\ \text{K.}$ radiating to a similar one at $300^\circ\ \text{K.}$, corrected for absorptions

and reflections at the rock-salt prism and plate by table 1. Intensity taken as 100,000 at $1.8\ \mu$.

Line 8 corrected intensities in the Nernst lamp spectrum approximating the conditions of line 7 but differing at the greater wave-lengths probably because of the decreasing absorption of energy by the lamp-blackened surface of the bolometer strip. (See discussion relative to comparison of black-body spectrum in section so headed in main body of paper).

It was found that the total energy scattered from any region is only about 3 per cent of that belonging to that region. The angle of incidence of the radiation on the image forming mirror was slightly less than 3° . The intensity of scattered energy falls off very rapidly to each side from the central image (see line 5). If the intensity is 100,000 in the central image, at an angle $10'$ it amounts to only $\frac{1}{4}$ of 1 per cent, at $20'$, $1/10$ of 1 per cent, then falling off more slowly, it amounts to $1/100$ of 1 per cent at $100'$. The total field energy (line 6) at $10'$ amounts to 5 per cent of that of the lamp spectrum upon which it is superposed, at $60'$ it amounts to nearly 50 per cent and at $100'$ to over 500 per cent. As already stated, in a solar spectrum formed with the same apparatus, the stray light at $10\ \mu$ was more than 100 times as intense as that which belonged there.

The above data were obtained with silver-on-glass mirrors, the surfaces of which were in excellent condition, freshly polished to a hard, compact surface. The following table shows a comparison with results obtained several months later after the mirrors were so badly tarnished as to be unfit for work in the visible spectrum. It will be noted that the scattering had increased relatively more for the greater deviations from the central image.

TABLE 18—INCREASE OF SCATTERING WITH TARNISHING

Deviation ($'$) ...	16	20	24	32	40	48	60	80	100
Wave-length (μ)	4.0	8.2	8.9	10.3	11.4	12.5	13.8	15.8	17.5
Increase ratio...	1.22	1.26	1.27	1.34	1.42	1.40	1.47	1.66	1.70

It would be of interest to know how far this work is applicable to determine stray light in other cases. The above results were a side issue of the more extensive investigation described in this report, and no more time could be spared to investigate this matter. In the work on the solar spectrum, involving resilvering of all the mirrors, a different distribution of energy in the spectrum, in which the upper infra-red much more greatly predominated over the longer wave portions than with the Nernst glower, produced curves of stray light which were the same within the limits of observational errors. Part

of the research involved the use of a different spectroscope using a rock-salt prism of 60° . In this spectroscope at $10\ \mu$ with a deviation of $150'$, (instead of the $30'$ with the 15° prism), practically no field light was observable upon the insertion of the $\frac{1}{2}$ cm. thick quartz plate. Now line 6 of table 16 shows that at $10\ \mu$ the deflection, which (with a rock-salt prism in both cases) should be dependent only on the wave-length, would be $400/100,000$; whereas the field light, if dependent only upon the deviation, would be perhaps $4/100,000$ or only 1 per cent of the true deflection. The deflection in the spectrum was so small at this wave-length (see fig. 6, upper part) that a deflection of 1 per cent of it would not have been detectable.

Two idiosyncrasies of the field light may be noticed: (1) Mention has been made of the error produced in the determination of the diaphragm values supposed to be caused by diffraction with the long wave-lengths and narrow slits. If this explanation were true, it would be expected that the values obtained at the same deviations with the field light would not show this error, since the field light is principally due to the more intense short wave-length energy. This was found to be so. (2) Another cause besides the natural decrease of energy with the greater wave-length tends to make the field light increasingly disturbing with the longer wave-lengths. For the absorption in the rock-salt of the true spectrum energy gets more and more effective as the wave-length increases; whereas the field light, being of short wave-lengths, passes through the prism almost unhindered.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

VOLUME 68, NUMBER 9

A NEW RIVER-DOLPHIN FROM CHINA

(WITH 13 PLATES)

BY

GERRIT S. MILLER, JR.



(PUBLICATION 2486)

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A NEW RIVER-DOLPHIN FROM CHINA

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(WITH 13 PLATES)

The skull and cervical vertebræ of a river-dolphin killed in Tung Ting Lake, about 600 miles up the Yangtze River, China, have recently been obtained by the National Museum from Mr. Charles M. Hoy. The following account of the animal has been given by Mr. Hoy in letters and in conversation: "Although I lived in China for several years I never saw this animal except in Tung Ting Lake and around its mouth. The natives give it the name *Pch Ch'i*, which they tell me means 'white flag', because the dorsal fin, which they liken to a flag, is so prominent when the animal comes to the surface to breathe. The sudden appearance of a school of these whitish dolphins close to a small boat is very startling. To the best of my knowledge this animal is found in large numbers only around the mouth of the Tung Ting Lake. In winter when the water of the lake is so low that there is scarcely more than the river channel left they are easily seen and are found in great numbers in bunches usually of three or four, but occasionally of as many as 10 or 12 individuals. They are often seen in shallow water working up the mud in their search for fish. The one I killed had about two quarts of catfish in its stomach. When shot it gave a cry like that of a water-buffalo calf. In summer the water rises to a height of 48 feet above its winter level. The mountain streams feeding the lake are then full, and the dolphins disappear. The natives say that in the late spring when the lake is rising the dolphins make their way up the small, clear rivers, and that these are their breeding grounds."

Contrary to what might have been anticipated this cetacean is not *Sotalia chinensis*. It is one of the "anomalous" porpoises of the family *Iniidae*.¹ Well represented and widely distributed in the Miocene and Pliocene this group is now so nearly extinct that only two living remnants are known: *Inia geoffrensis* in the Amazon and

¹ See True, Proc. Amer. Philos. Soc., Vol. 47, p. 391, 1908.

Orinoco and the present animal in the Yangtze. The Chinese river-dolphin may be named and described as follows:

LIPOTES, gen. nov. (Iniidæ)

Type.—*Lipotes vexillifer*, sp. nov.

Diagnosis.—General structure of skull as in *Inia*, but beak bowed upward, basicranial axis not conspicuously bent downward from axis of beak, proximal extremity of intermaxillary thin and plate-like, not forming a raised anterior border to narial aperture, mandibular symphysis barely equal to free portion of ramus; teeth about 130, essentially uniform throughout the toothrow, the form of the crown and character of the enamel-wrinkling much as in the median teeth of *Inia*, but root not thickened, the entire tooth resembling that of the Miocene North American "*Schizodelphis*"; dorsal fin large, triangular.

Skull.—While the skull (plates 2, 4, 6, 8, 9) presents more features of likeness to that of *Inia* (plates 3, 5, 7, 8, 10) than to that of any other known cetacean, there are obvious differences between the South American and Chinese river-dolphins in all the details of cranial structure. The more important of these have been mentioned. Among the others the following seem worthy of note:

DORSAL ASPECT

(Plates 2 and 3)

Lipotes

Narial aperture slit-like in front.

Maxillary crest nearly horizontal over temporal fossa, strongly bent upward over orbit.

Area between lambdoid crests wider than high.

Breadth across maxillary crests through posterior border of narial opening slightly greater than interorbital breadth.

Region between crest and nares slightly concave.

Intermaxillary convex laterally in front, concave behind toothrow.

Protuberance behind nares smaller than narial openings.

Nasals broader than high, not overhung by frontals.

Entire condyles visible when skull is viewed from directly above.

Inia

Narial aperture broadly rounded in front.

Maxillary crest essentially in one plane throughout.

Area between lambdoid crests higher than wide.

Breadth across maxillary crests through posterior border of narial opening much less than interorbital breadth.

Region between crest and nares deeply concave.

Intermaxillary convex laterally throughout.

Protuberance behind nares larger than narial openings.

Nasals higher than broad, overhung by frontals.

Condyles hidden when skull is viewed from directly above.

LATERAL ASPECT

(Plates 4 and 5)

Lipotes

Crest turned abruptly upward over orbit.

Length of orbit nearly half that of temporal fossa.

Glenoid process strongly curved forward.

Squamosal tapering anteriorly.

Lateral groove on beak well defined, but wide and shallow.

Inia

Crest not turned abruptly upward over orbit.

Length of orbit scarcely one-fifth that of temporal fossa.

Glenoid process not strongly curved forward.

Squamosal enlarged anteriorly.

Lateral groove on beak narrow, ill defined.

VENTRAL ASPECT

(Plates 6 and 7)

Distance from last tooth to maxillary notch much greater than width of beak at last tooth.

Beak narrowed between toothrow and maxillary notch as in *Pontistes*.

Keel flattening out at level 45 mm. behind last tooth.

Edge of basal wing deeply notched so that pterygoid is nearly or quite cut off from contact with basi-sphenoid.

Depression on squamosal at inner side of glenoid area sharply defined, narrowed in front.

Distance from last tooth to maxillary notch less than width of beak at last tooth.

Beak not narrowed between toothrow and maxillary notch.

Keel flattening out at level of last tooth.

Edge of basal wing entire; pterygoid broadly in contact with basi-sphenoid.

Depression on squamosal at inner side of glenoid area ill defined, wider in front than behind.

OCCIPITAL ASPECT

(Plate 8)

Supraoccipital area wider than high, essentially flat; a distinct median ridge extending from lambdoid crest nearly to foramen magnum.

Area of foramen magnum about half that of one supraoccipital.

Two deep furrows in region between paroccipital process and glenoid process (clearly shown on right-hand side of figure).

Supraoccipital area higher than wide, each bone noticeably convex both vertically and laterally; a median furrow extending from near foramen magnum to above middle.

Area of foramen magnum about one-fourth that of one supraoccipital.

Only one deep furrow in region between paroccipital process and glenoid process.

MANDIBLE

(Plates 4, 5, 9 and 10)

Lipotes

Anterior edge of dental foramen about 45 mm. behind last tooth.

Distance from symphysis to last tooth much greater than distance between last tooth of opposite rows.

Height through coronoid equal to about one-third length of free portion of mandible.

Coronoid abruptly rounded.

Angular process with broadly rounded projection.

A conspicuous median groove between toothrows.

Inia

Anterior edge of dental foramen about 20 mm. behind last tooth.

Distance from symphysis to last tooth equal to distance between last tooth of opposite rows.

Height through coronoid equal to about half length of free portion of mandible.

Coronoid broadly rounded.

Angular process with sharp, narrow projection.

No median longitudinal groove between toothrows.

The pterygoids have probably been injured in the narial region. It is therefore impossible to be certain whether their entire structure is exactly the same as in *Inia*. At base it is undoubtedly similar to that in the South American animal. The backward-turned portion which fits against the vomer in *Inia* is not present, though traces of the ridge against which it probably was applied can be distinctly seen. The structure actually present in the Chinese animal could be made from that of *Inia* by breaking away the bones to the level of the edge of the internarial septum. This is clearly seen on comparing plate 6 with Abel's figure of a skull of *Inia* in which such mutilation has actually taken place (Mém. Mus. roy. Hist. Nat. Belg., Vol. 1, pl. 3, fig. 3, 1901). The outer plate associated with the pterygoid in the narial region appears to be nearly perfect. It is like that of *Inia* except that it is shorter and without fenestration. Posteriorly the pterygoids are much narrowed by the development of a broad notch in the margin of the basal wing. The presence of this notch together with a widening of the expanded posterior portion of the vomer nearly or quite excludes the pterygoids from contact with the basipheneoids.

A very noticeable feature of the skull is the position of the nares. (Compare pls. 2 and 3.) The anterior margin of the aperture is at about the middle of the cranium in *Lipotes*, decidedly in front of the middle in *Inia*. Yet when the anterior margin of the nares is compared with the temporal fossa these conditions appear to be reversed. Probably the backward bulge to the occipital region in *Inia* accounts for the first peculiarity, and a difference in the form of the frontal explains the second.

Cervical vertebrae.—The cervical vertebrae (pls. 11 and 12) while agreeing with those of *Inia* (pls. 11 and 13) in the complete separation of all the bones of the series differ from those of the South American dolphin in so many details of form, some of which may prove to be subject to individual variation, that a complete enumeration of the peculiarities will not be undertaken. The more general differences, among those which appear to be of importance, are as follows: In *Inia* the lateral canal is open behind the third vertebra; in *Lipotes* it is essentially closed throughout. In *Inia* the centra and the neural openings tend to be higher than wide; in *Lipotes* wider than high. In *Inia* the neural spine is large and high in both second and seventh vertebra; in *Lipotes* it is broad and low in the second, scarcely developed in the seventh. In *Inia* the lower transverse process of the fourth vertebra is enlarged and curved forward; in *Lipotes* it is reduced and curved backward. In *Inia* the lower transverse process of the fifth vertebra is straight and greatly enlarged; in *Lipotes* it is curved forward and slightly enlarged. In *Inia* the lower transverse process of the sixth vertebra is reduced; in *Lipotes* it is the largest of the series. In *Inia* the seventh vertebra has no lower transverse process; in *Lipotes* the lower transverse process is fully developed, its extremity joined to the upper process. Further comparison will be found below:

FIRST CERVICAL

Lipotes

Basal process slightly developed, its length not equal to longitudinal diameter of centrum.

Upper transverse process an inconspicuous ridge on base of pedicle.

Inia

Basal process large, its length about twice as great as longitudinal diameter of centrum.

Upper transverse process a conspicuous knob below base of pedicle.

SECOND CERVICAL

Spinous process with upper-anterior margin sloping gradually and in approximately the same line as that of first cervical.

Transverse process narrow and long, partly or completely perforate.

Spinous process with anterior margin sloping very abruptly and forming a conspicuous angle with that of first cervical.

Transverse process broad and short, imperforate.

THIRD CERVICAL

Neural arch open above.

Transverse processes long, united, their extremities nearly at level of lower border of centrum; lateral canal relatively small.

Neural arch closed above.

Transverse processes short, separate or nearly so, their extremities about at level of centrum; lateral canal relatively large.

FOURTH CERVICAL

Lipotes

General outline about as wide as high.

Transverse processes united, not very different from those of third cervical, but more slender.

Inia

General outline higher than wide.

Transverse processes separate, conspicuously different from those of third cervical, the lower greatly broadened and curved forward under transverse process of third cervical.

FIFTH CERVICAL

Transverse processes separate, the lower with a distinct projection indicating the outline of the lateral canal; extremity of lower process thickened and curved forward under transverse process of fourth cervical.

Transverse processes separate, the outline of the canal not indicated; lower process enlarged, straight, the extremity much thickened.

SIXTH CERVICAL

No definite neural spine.

Lower transverse process with small projection indicating boundary of lateral canal; extremity of lower process greatly expanded into an oblique, plate-like mass which extends slightly beyond level of anterior face of centrum and decidedly beyond level of posterior face as well as beyond level of lower border.

A small neural spine.

No indication of boundary of canal; lower transverse process small, not extending beyond level of anterior and posterior faces of centrum or below level of its lower border.

SEVENTH CERVICAL

Neural spine slightly developed, its height less than half that of neural canal.

Transverse processes united, completely closing the lateral canal.

Neural spine greatly developed, its height about twice that of neural canal.

Upper transverse process alone present, the position of the base of lower process indicated by a faint thickening on edge of centrum.

Teeth.—The teeth are probably more numerous than is usual in *Inia*, they are smaller relatively to the width of the palate, and they project more at the sides of both beak and lower jaw. These general peculiarities are well shown by the plates. The form of the exposed portion of all the teeth is essentially like that of the median teeth in the South American animal. The rugosity of the enamel is nearly as evident as in *Inia*, it differs from that of *Inia* in a structure which may perhaps be best described as more reticulate and less nodular.

The form of an entire tooth from near middle of toothrow (fig. 1, *a, b*) is strikingly different from that of a corresponding tooth of *Inia* (fig. 1, *c, d*). It more nearly resembles that of the teeth from the Miocene of Maryland figured by Cope (Amer. Nat., Vol. 24, p. 607, July, 1890) as those of *Rhabdosteus* but later referred by True (Proc. Acad. Nat. Sci., Philadelphia, 1908, p. 29, April 22, 1908) to *Schizodelphis*. The root through the greater part of its extent is not conspicuously wider than the crown. It is compressed laterally, while the crown is compressed antero-posteriorly. Between the root and crown there is a distinctly indicated neck, but this constriction is

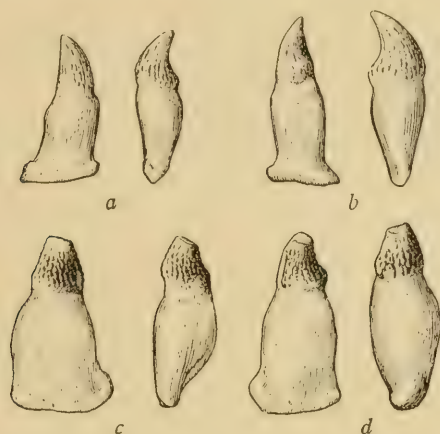


FIG. 1.—*a. Lipotes vexillifer*, 16th maxillary tooth. *b. Lipotes vexillifer*, 16th mandibular tooth. *c. Inia geoffrensis*, 15th maxillary tooth. *d. Inia geoffrensis*, 13th mandibular tooth. All figures natural size. View at left of each pair is from inner side, that at right is from behind. The teeth of *Inia* are worn away at tip.

neither so long nor so well developed as in the Maryland *Schizodelphis*.¹ At base, the most compressed region, the root abruptly widens to form a sharply defined anterior and posterior projection, the combined function of which is to anchor the tooth firmly in the alveolus. At first sight these projections suggest the final remnants of two fangs completely joined through the greater part of the root, but sections of that part of the tooth fail to reveal any traces of

¹ It seems very doubtful whether these teeth should be referred to the same genus as those figured by Probst (Jahreshefte Ver. vaterländ. Naturk. Württemberg, Vol. 48, pl. 3, figs. 11-14, 1886) from Württemberg, Germany.

internal structures to support this view. In the teeth at the extremities of the toothrows the anterior projection is less developed. The resulting form suggests that of some of the teeth from the upper Miocene of northern Italy figured by Dal Piaz under the name *Cyrtodelphis sulcatus* (Palæont. Ital., Vol. 9, pl. 31, 1903). In the median teeth of *Inia* (fig. 1, *c*, *d*) the root is expanded to about double the diameter of the crown. The basal projections, though present and efficient in retaining the teeth in the socket, are masked by the general widening.

Remarks.—The genus *Lipotes* differs too widely from its only known living relative, *Inia*, to require special comparisons beyond those which have already been made. Externally its most conspicuous peculiarity is the presence of the large triangular dorsal fin. In the skull many of the differences between the two animals are correlated with the opposite curvature of the beaks. Opposite tendencies are also to be observed in the teeth, those of *Inia* having specialized on strength and robustness, those of *Lipotes* on wideness of grasp (compare especially the palatal aspect of skull shown in plates 6 and 7).

Among the described fossil dolphins there appears to be no genus whose relation to *Lipotes* is especially intimate. Reference has already been made to the likeness of the teeth to those of the American *Schizodelphis*. There is also a noticeable similarity between the base of the beak and that of *Pontistes* as figured by Burmeister, but this is obviously a chance resemblance as *Pontistes* is no longer regarded as one of the *Iniidæ*.

LIPOTES VEXILLIFER, sp. nov.

Type.—Skull and cervical vertebræ of adult male, No. 218293, U. S. National Museum. Collected in Tung Ting Lake, China, February 18, 1916, by Charles M. Hoy.

Diagnosis.—A porpoise about two and one-half meters in length, greatest length of skull about 500 mm.; color pale blue-gray above, white below.

Measurements.—Cranial measurements of type. Condylobasal length, 514 (526)¹; basal length, 510 (515); from middle of supraoccipital to tip of beak, 481 (497); rostrum, 350 (352); distance from tip of beak to nares, 390 (403); distance from last tooth to apex of

¹ Measurements in parentheses are those of a somewhat older skull of *Inia geoffrensis*, No. 49582, U. S. National Museum.

maxillary notch, 77 (48); breadth of beak between maxillary notches, 96 (110); breadth of beak half way between last tooth and apex of maxillary notch, 55 (77); breadth of beak at last tooth, 60 (62); breadth of beak at middle, 37 (35); breadth of intermaxillaries at middle, 21 (27); greatest breadth of intermaxillaries proximally, 62 (64); interorbital breadth, 128 (144); breadth across maxillary crests at level of posterior border of nares, 137 (96); glenoid breadth, 199 (223); median depth of braincase through prominence behind nares, 125 (158); occipital depth, 114 (142); depth of rostrum at level of last tooth, 34 (44); depth of rostrum at middle of toothrow, 21 (37); length of temporal fossa, 110 (153); depth of temporal fossa, 80 (89); length of orbit, 45 (30); mandible, 471 (465); mandibular symphysis, 225 (268); coronoid-angular depth, 88 (113); depth of mandible at level of last tooth, 35 (47); depth of mandible at middle of toothrow, 24 (32); upper toothrow, 278 (312); lower toothrow, 285 (315); largest upper teeth, height from base of enamel, 8.6 (-), diameter at base of enamel, 5×7 (7.6×10.9); largest lower teeth, height from base of enamel, 9 (-), diameter at base of enamel, 5×7 (8×11).

Cervical vertebræ of type.—ATLAS: greatest breadth, 81.5 (84.1); greatest median depth, 70.8 (67.5); breadth of spinal canal, 34.6 (28.9); median depth of spinal canal, 41.0 (39.5); depth of centrum, 15.8 (15.1); thickness of centrum, 17.3 (19); articular surface for condyle, height 40.3 (41.8), width, 32.0 (39.2). AXIS: greatest breadth, 93.3 (88.5); greatest median depth, 68.8 (76.5); breadth of spinal canal, 27.6 (25.5); median depth of spinal canal, 24.6 (22.1); breadth of centrum, 39.3 (42.6); depth of centrum, 26.1 (34.6); thickness of centrum, 18.7 (22.8). THIRD CERVICAL: greatest breadth, 76.8 (75.6); greatest median depth, 57.0 (62.0); breadth of spinal canal, 26.1 (21.1); median depth of spinal canal, 26.3 (22.6); breadth of centrum, 36.2 (40.3); depth of centrum, 29.8 (21.7); thickness of centrum, 12.0 (11.0); breadth of lateral canal, 9.0 (8.6); depth of lateral canal, 7.2 (7.2). FOURTH CERVICAL: greatest breadth, 69.3 (67.5); greatest median depth, 51.6 (61.7); breadth of spinal canal, 25.9 (22.0); median depth of spinal canal, 18.5 (19.8); breadth of centrum, 32.5 (36.8); depth of centrum, 30.0 (37.8); thickness of centrum, 10.1 (11.6); breadth of lateral canal, 9.6 (-); depth of lateral canal, 8.0 (10.7). FIFTH CERVICAL: greatest breadth, 61.4 (73.9); greatest median depth, 50.6 (61.6); breadth of spinal canal, 30.6 (26.6); depth of spinal canal, 17.5 (17.6); breadth of centrum, 32.7 (36.8); depth of centrum, 31.5 (37.5); thickness

of centrum, 11.0 (12.5); depth of lateral canal, 12.6 (-). SIXTH CERVICAL: greatest breadth, 69.6 (72.4); greatest median depth, 54.2 (66.7); breadth of spinal canal, 33.0 (29.6); median depth of spinal canal, 17.6 (17.8); breadth of centrum, 34.7 (36.2); depth of centrum, 31.5 (40.0); thickness of centrum, 12.4 (14.2); depth of lateral canal, 13.7 (-). SEVENTH CERVICAL: greatest breadth, 109.5 (109.8); greatest median depth, 63.2 (106.7); breadth of spinal canal, 33.6 (29.5); median depth of spinal canal, 20.2 (20.2); breadth of centrum, 32.6 (41.2); depth of centrum, 31.8 (37.6); thickness of centrum, 15.5 (16.2); breadth of lateral canal, 27.3 (-); depth of lateral canal, 12.0 (-).

Remarks.—The general form of *Lipotes vexillifer* is sufficiently well indicated by the photograph and tracing in plate 1. A few details concerning the external characters are, however, not entirely clear. In the photograph reproduced the posterior border of the flipper appears to be entire, while in the one from which the tracing was made it is evidently notched and angled at the distal extremity. There is a similar doubt as to the exact outline of the flukes.

With the specimen and photographs Mr. Hoy sent these notes on the freshly killed animal: "Length, 7 ft. 6 in.; girth, several inches in front of dorsal fin, 4 ft. 6 in.; total number of vertebræ, 45; color, back blue-gray, belly white; eyes very small; ears like pin pricks; blowhole rectangular, at depth of one inch it divides into two passages".

In the type the dental formula is $\frac{33-32}{33-31} = 129$. The individual variation in the number of teeth may eventually be found to be as great as in *Inia*, where the range, according to Flower, is from 104 to 132 (Trans. Zool. Soc. London, Vol. 6, p. 95, 1867). The smaller size of the teeth and the apparent specialization of the entire dentition for seizing and grasping rather than for strength make it appear probable that the average number will prove to be greater than in the South American animal. Further material will be required to show whether such is actually the case.

EXPLANATION OF PLATES

PLATE 1

Lower figure, *Lipotes vexillifer*. Photograph of freshly killed animal by Charles M. Hoy.

Upper figure, tracing from another photograph by Mr. Hoy.

PLATE 2

Lipotes vexillifer, type. Dorsal view of skull (about $\times .30$).

PLATE 3

Inia geoffrensis, No. 49582, U. S. Nat. Mus. Dorsal view of skull (about $\times .30$).

PLATE 4

Lipotes vexillifer, type. Lateral view of skull (about $\times .30$).

PLATE 5

Inia geoffrensis, No. 49582, U. S. Nat. Mus. Laetral view of skull (about $\times .30$).

PLATE 6

Lipotes vexillifer, type. Palatal view of skull (about $\times .30$).

PLATE 7

Inia geoffrensis, No. 49582, U. S. Nat. Mus. Palatal view of skull (about $\times .30$).

PLATE 8

Upper figure, *Lipotes vexillifer*, type. Occipital view of skull (about $\times .30$).

Lower figure, *Inia geoffrensis*, No. 49582, U. S. Nat. Mus. Occipital view of skull (about $\times .30$). Tilted slightly forward; the extremity of the frontal should just clear the squamosal.

PLATE 9

Lipotes vexillifer, type. Mandible (about $\times .30$).

PLATE 10

Inia geoffrensis, No. 49582, U. S. Nat. Mus. Mandible (about $\times .30$).

PLATE II

Upper figure, *Lipotes vexillifer*, type. Cervical vertebræ from the left side (about $\times .57$).

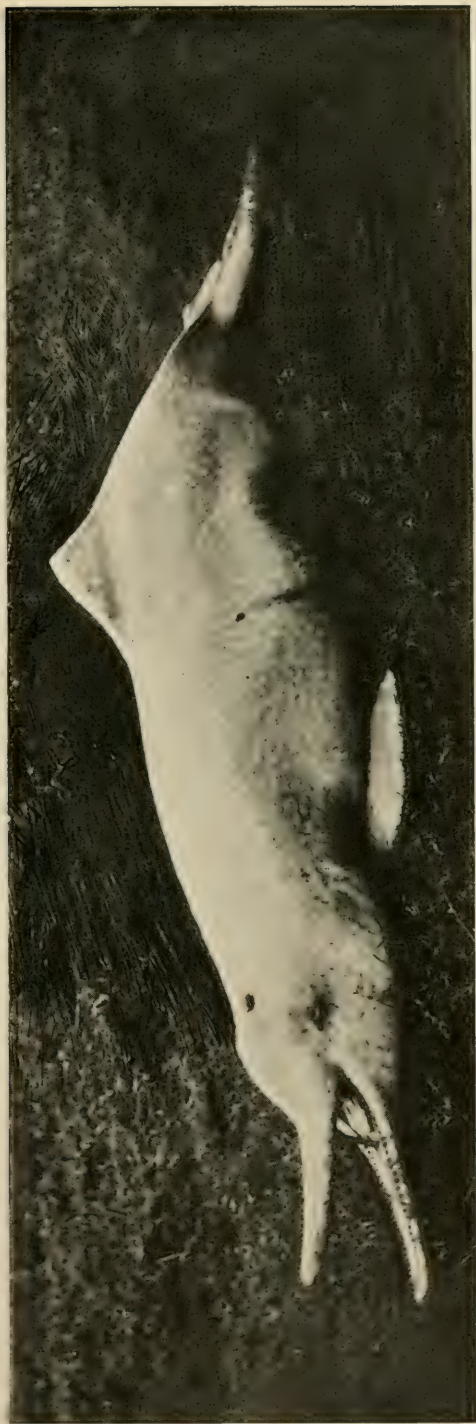
Lower figure, *Inia geoffrensis*, No. 49852, U. S. Nat. Mus. Cervical vertebræ from left side (about $\times .57$).

PLATE I2

Lipotes vexillifer, type. Cervical vertebræ, anterior surface (about $\times .63$).

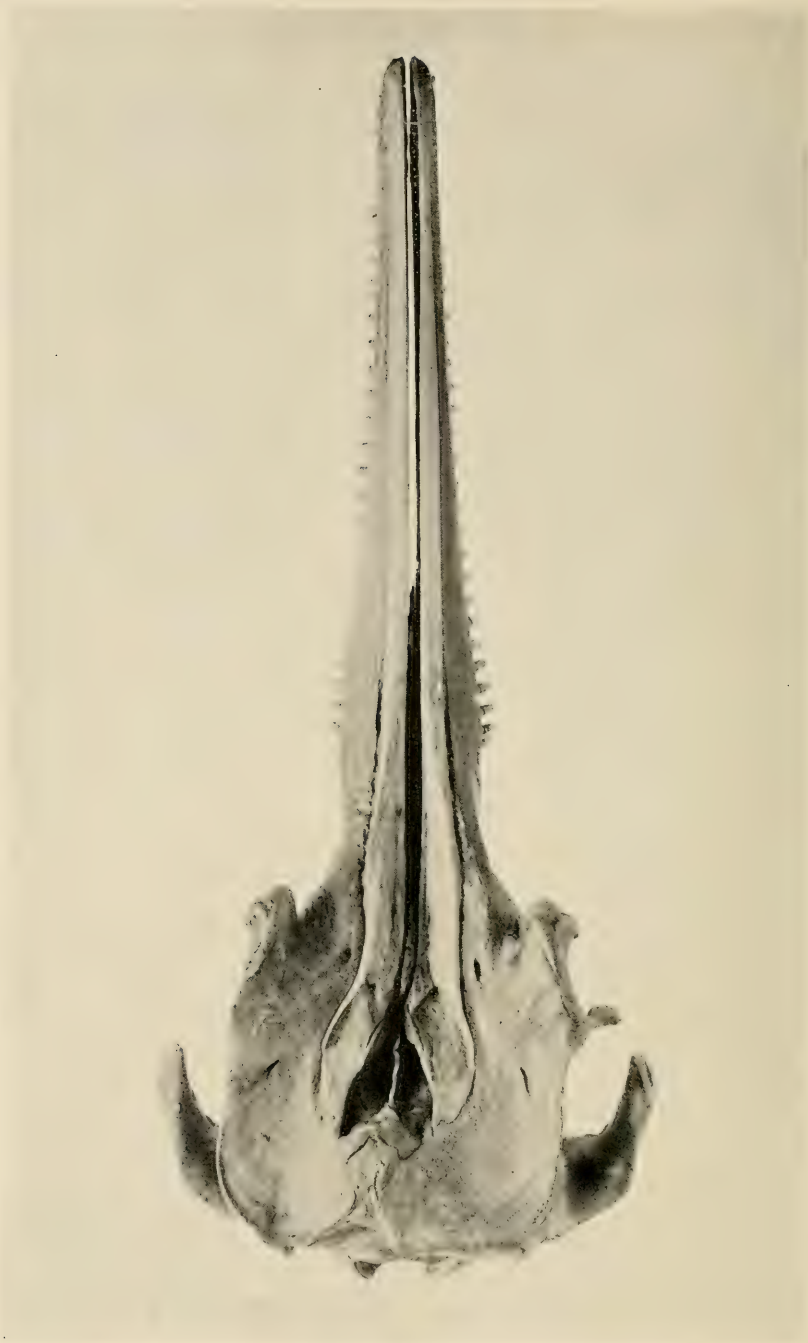
PLATE I3

Inia geoffrensis, No. 49582, U. S. Nat. Mus. Cervical vertebræ, anterior surface (about $\times .63$).



LIPOTES VEXILLIFER
(Greatly reduced)

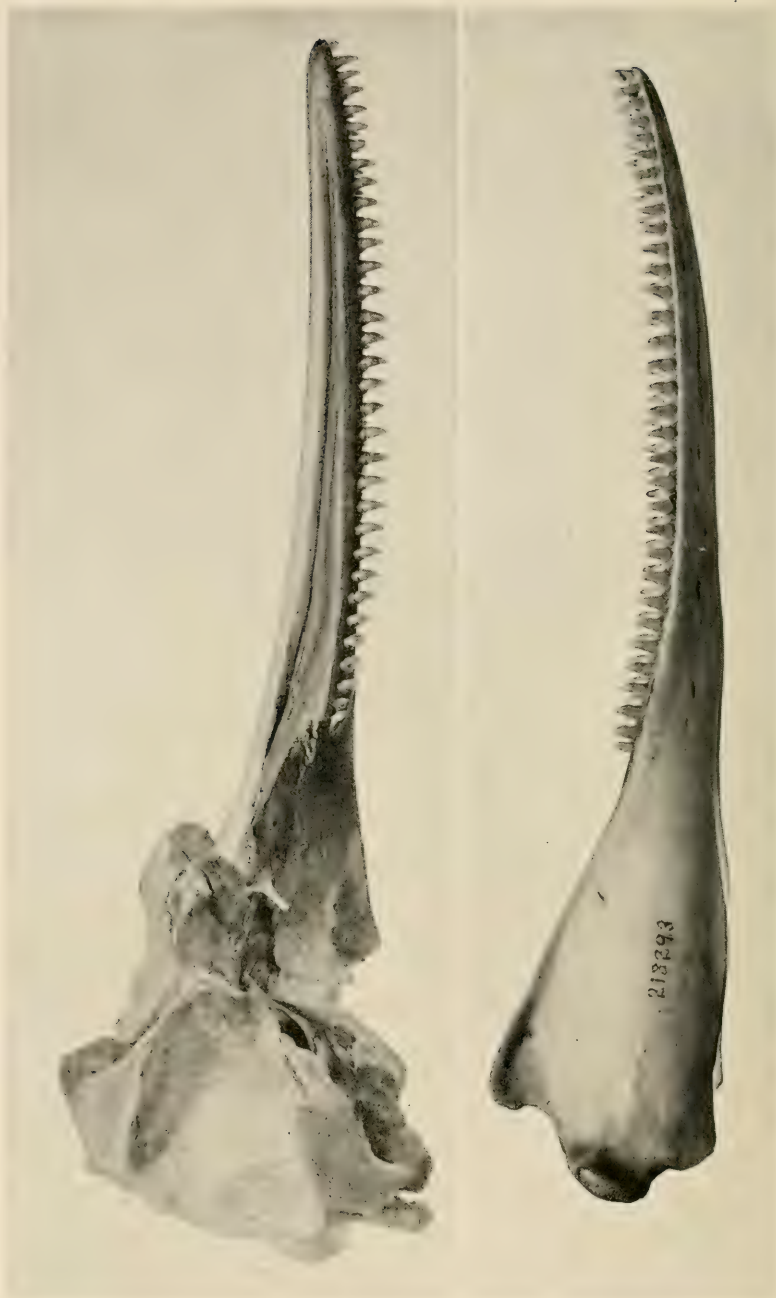




LIPOTES VEXILLIFER
(About $\times .30$)



INIA GEOFFRENSIS
(About $\times 30$)



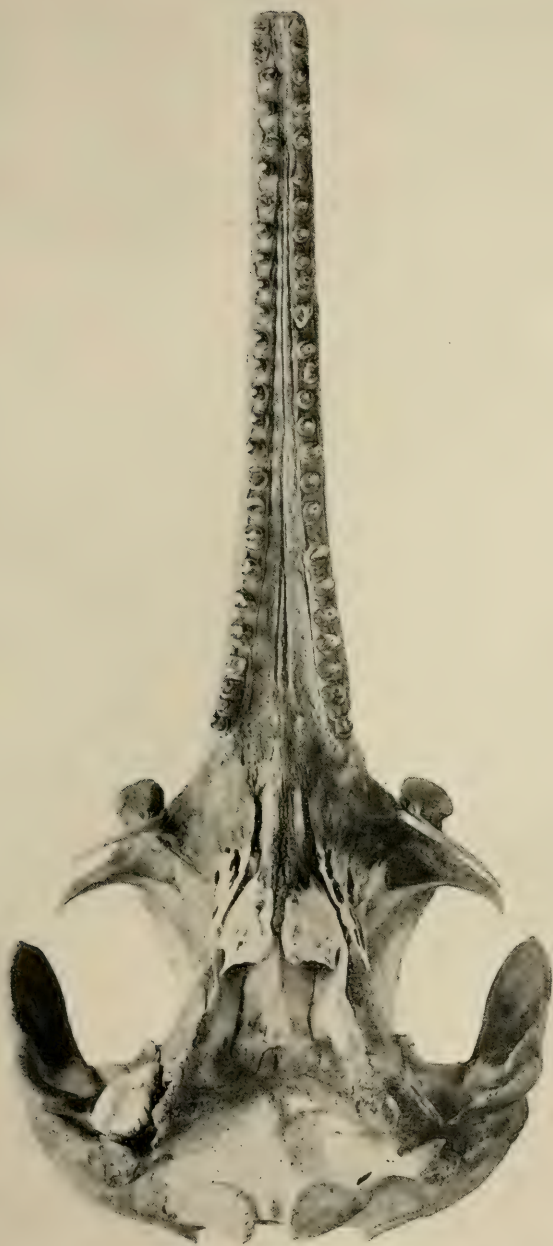
LIPOTES VEXILLIFER
(About $\times 30$)



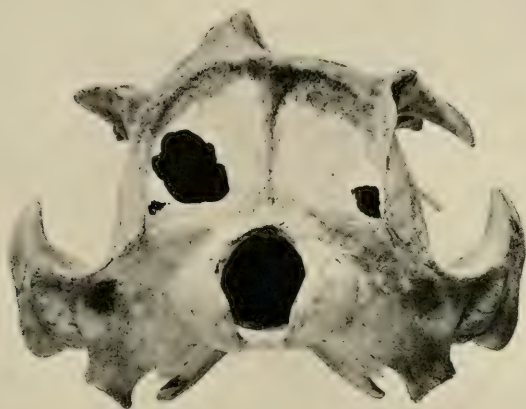
INIA GEOFFRENSIS
(About $\times .30$)



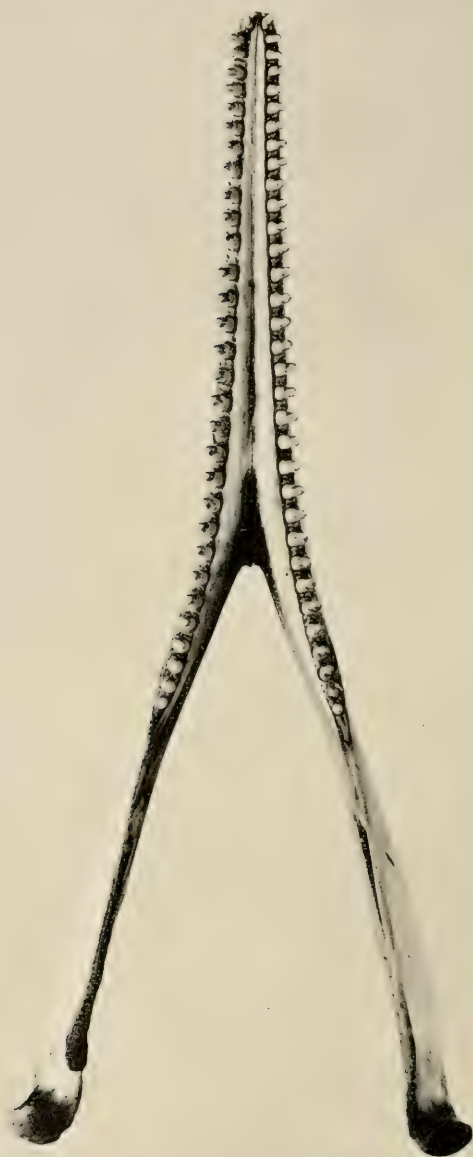
LIPOTES VEXILLIFER
(About $\times .30$)



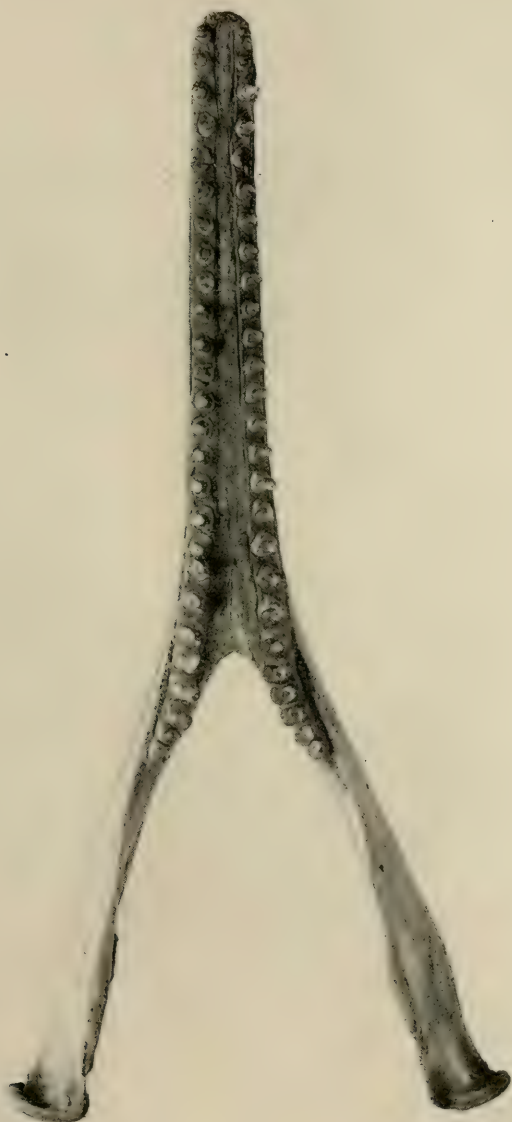
INIA GEOFFRENSIS
(About $\times .30$)



LIPOTES VEXILLIFER
INIA GEOFFRENSIS
(About $\times .30$)



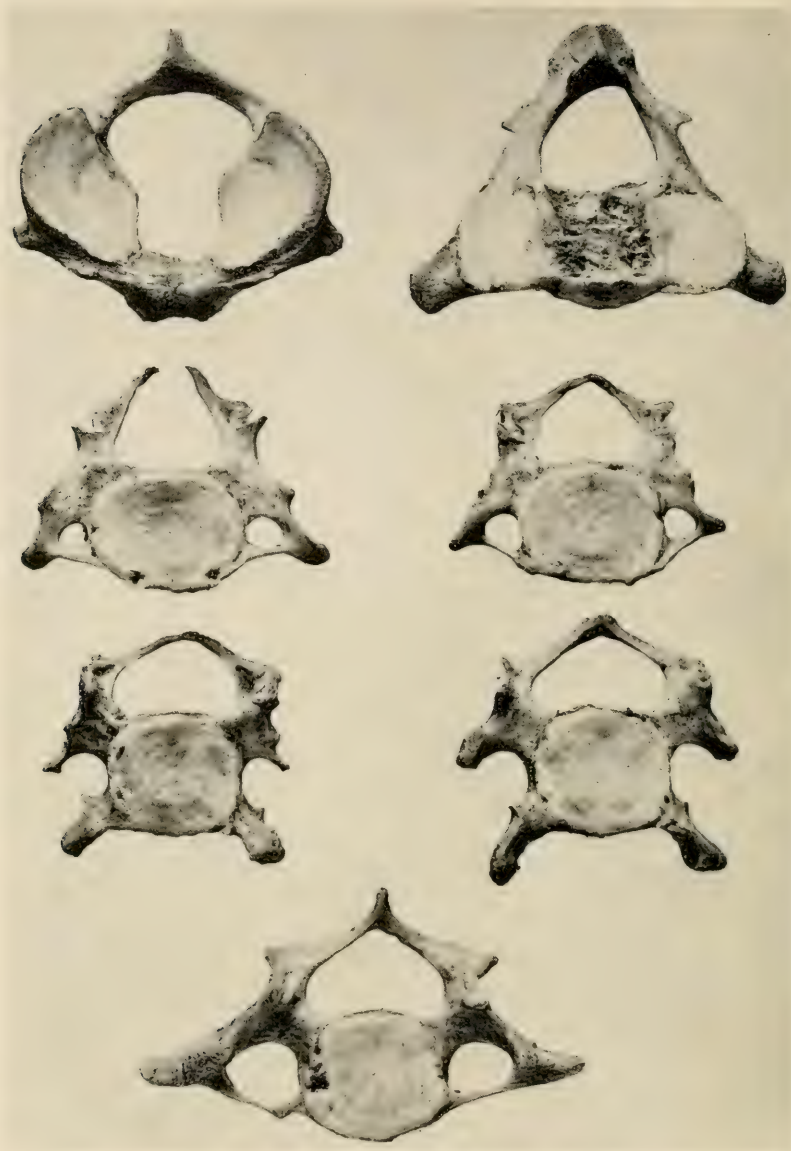
LIPOTES VEXILLIFER
(About $\times .30$)



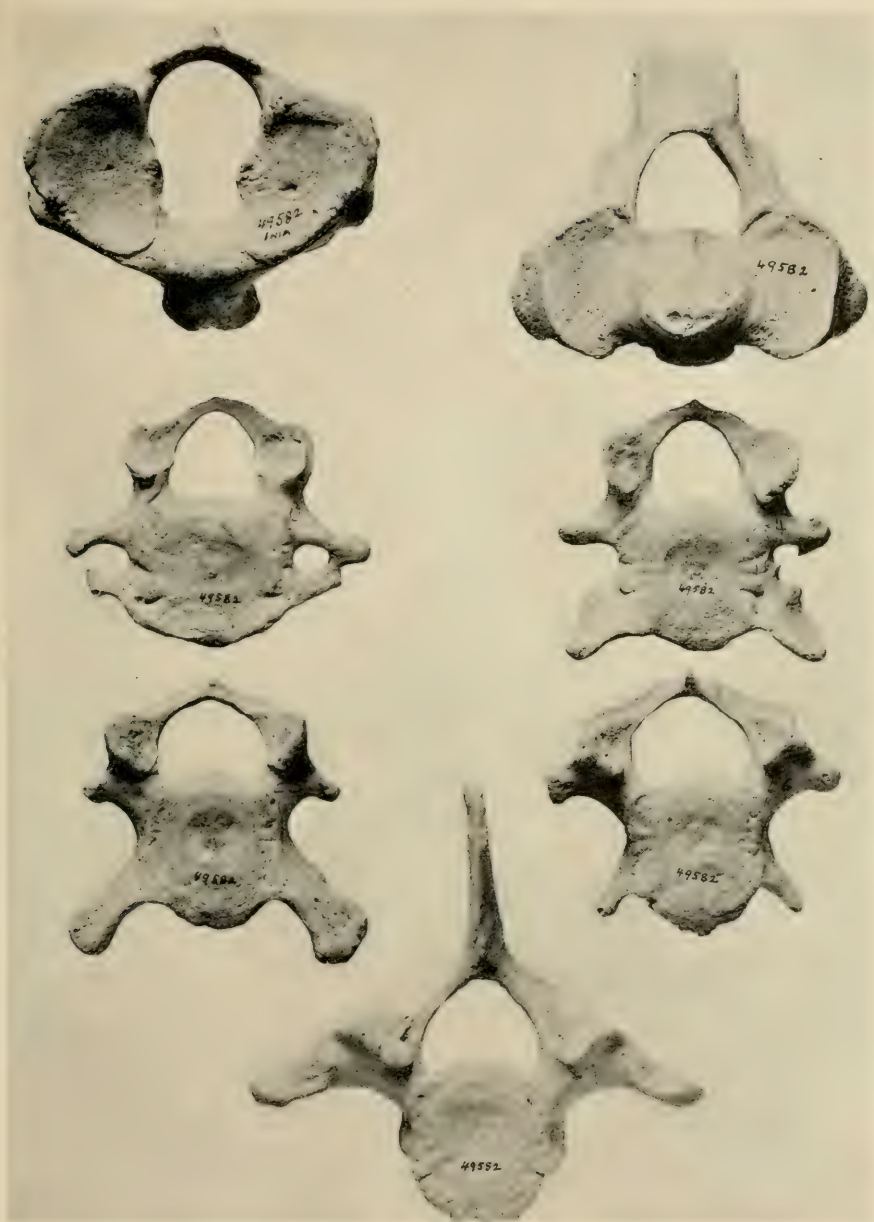
INIA GEOFFRENSIS
(About $\times .30$)



LIPOTES VEXILLIFER
INIA GEOFFRENSIS
(About $\times .57$)



LIPOTES VEXILLIFER
(About $\times .63$)



INIA GEOFFRENSIS
(About $\times .63$)

SMITHSONIAN MISCELLANEOUS COLLECTIONS

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NEW RODENTS FROM BRITISH EAST AFRICA

BY

N. HOLLISTER



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NEW RODENTS FROM BRITISH EAST AFRICA

By N. HOLLISTER

The following hitherto undescribed subspecies of rodents have been found in the collections made by the Smithsonian African Expedition in 1909, and by the Rainey African Expedition of 1911 and 1912.

RATTUS COUCHA TINCTUS, subsp. nov.

Type from Kaimosi, Kavirondo, British East Africa; adult male (teeth moderately worn), skin and skull, U. S. Nat. Museum No. 183294. Collected January 24, 1912, by Edmund Heller. Orig. No. 5188.

Diagnosis.—A large, dark-colored subspecies of *Rattus coucha* with the underparts dark grayish buff, drab, or tawny olive (apparently never grayish white as in the related forms).

Color of type specimen.—Entire upperparts blackish brown, slightly sprinkled with dark clay color. The hairs are broadly dark slate at bases, many of them blackish to tips, while others have a terminal or subterminal ring of clay color or dark tawny. Sides paler than back, with more tawny and less black. Underparts only slightly lighter than sides, the hairs slate at bases and tipped with clay color, with considerable dark from the undercolor showing through. Arms and legs dark brownish to wrist and heel, the hands and feet creamy whitish. Tail blackish brown, slightly lighter at base below.

This is an average specimen in color, but some skins in the series are somewhat brighter, with more tawny above or below. All agree in having intensely colored underparts only slightly differentiated from the color of the flanks.

Skull and teeth essentially as in *Rattus coucha uganda*, but averaging more robust.

Measurements.—The type, with dimensions of an older male (No. 183295) in parentheses: Head and body, 160 (160) mm.; tail vertebrae, 133 (148); hind foot from dry skin, 26 (30); greatest length of skull, 34.6 (36.1); condylobasal length, 33.3 (35.0); zygomatic breadth, 16.8 (17.9); mastoid breadth, 13.6 (14.3); upper tooth row, alveoli, 5.5 (5.8).

Remarks.—In a large collection of specimens of multimammate rats from many parts of eastern Africa, the series of nineteen skins from Kaimosi is conspicuous on account of the generally dark color above and because of the absence of any specimens with light-colored underparts. The skins and skulls average larger in size than those of neighboring forms. The new subspecies is most closely related to *Rattus coucha ungandæ* (de Winton), described from Entebbe and represented in the National Museum collection by numerous examples from the north shore of Victoria Nyanza and Unyoro.

PEDETES SURDASTER LARVALIS, subsp. nov.

Type from Ulukenia Hills, Athi Plains, British East Africa; adult female, skin and skull, U. S. Nat. Museum No. 163304. Collected November 21, 1909, by J. Alden Loring. Orig. No. 8250.

Diagnosis.—Like *Pedetes surdaster surdaster* of the Naivasha Plains but less richly colored and skull with much deeper face. A supraorbital elevation on each side of the median depression in frontals, on the anterior portion of frontal bone and at the base of nasal, gives the profile view an evenly rounded outline from mastoid to nasal [in typical *surdaster* the braincase is higher and the sinciput low, so that a profile view presents a very uneven line, much raised posteriorly and with a decided depression over the lachrymal region in the center]. Most of the bones of the face are involved in the producing of the much greater depth of the entire anterior portion of the skull, which is conspicuous when compared in profile or from anterior view with skulls of typical *surdaster*. The rostrum is much deeper and the antorbital region, including the foramen and antorbital plate, much higher and comparatively narrow. Suture between frontals and parietals nearly straight across skull, with only slight anterior convexity [in *surdaster* always with distinct and usually pointed salient]. Size essentially as in *surdaster*.

Measurements of type.—Head and body, 370 mm.; tail vertebrae, 427; hind foot, 159; ear, 82. Skull: Condylbasal length, 78.2; zygomatic breadth, 55.2; greatest breadth nasals, 21.7; height of skull in front of orbits, from anterior alveolar border to highest point on crown directly above lachrymal bone, 36.2 [in numerous specimens of typical *surdaster*, 30.5 to 32.4]; mastoid breadth, 45.4; upper tooth row, crowns, 16.3.

Remarks.—Four specimens of this new form from the Athi Plains have been compared with forty-six specimens of *Pedetes surdaster surdaster* from Naivasha Station, near the type locality.

PEDETES SURDASTER CURRAX, subsp. nov.

Type from Kabalolot Hill, Sotik, British East Africa; adult male, skin and skull, U. S. Nat. Museum No. 181762. Collected May 7, 1911, by Edmund Heller. Orig. No. 1802.

Diagnosis.—Decidedly more yellowish, less reddish, than *Pedetes surdaster surdaster*, and with longer tail. Skull with upper outline in profile as in *surdaster*, but with the high rostrum and antorbital region in general more like *P. s. larvalis*. Mastoids more enlarged than in either, the skull with greater mastoid breadth.

Measurements of type.—Head and body, 400 mm.; tail vertebrae, 48.0; hind foot, 15.7; ear, 7.3. Skull: Condylbasal length, 75.3; zygomatic breadth, 55.7; greatest breadth nasals, 19.0; height of skull in front of orbits, from anterior alveolar border to highest point on crown directly above lachrymal bone, 33.6; mastoid breadth, 46.1 [in numerous skulls of true *surdaster* from 41.9 to 43.8]; upper tooth row, crowns, 15.9.

Remarks.—This new form is based on a single specimen which cannot be matched for color or great mastoid breadth of skull by any specimen out of a series of nearly fifty specimens from the type locality of *surdaster*. All three forms of *surdaster*, from the Sotik, Naivasha Plains, and Athi Plains, differ from the South African *P. cafer* in the shallowness of the anterior palatine depression.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

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THE MARINE ALGAE AND MARINE
SPERMATOPHYTES OF THE TOMAS
BARRERA EXPEDITION TO CUBA

BY
MARSHALL A. HOWE



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THE MARINE ALGAE AND MARINE SPERMATOPHYTES OF THE TOMAS BARRERA EXPEDITION TO CUBA

By MARSHALL A. HOWE

The plants named in the following brief report were collected on the western coast of Cuba in May and June, 1914, by Mr. John B. Henderson, Regent of the Smithsonian Institution, and Dr. Paul Bartsch, Curator, Division of Marine Invertebrates, of the United States National Museum. An illustrated popular account of the expedition has been written by Mr. Henderson and published in book form under the title, "The Cruise of the Tomas Barrera,"¹ the expedition taking its name from that of the Cuban schooner generously placed at the disposal of the explorers by its owners. The collecting of algae was incidental to the activities of the expedition in zoological lines, and while the list of marine algae obtained is not a long one it is longer than any hitherto published for the island of Cuba and includes a considerable number of species not hitherto attributed to this island, though some of the latter are represented in unreported collections made by the writer in the vicinity of Guantanamo Bay in 1909. Included in the list are one species (*Phormidium Hendersonii*) which the writer is venturing to describe as new and one species (*Sarcomenia filamentosa*) which was previously known from the type specimens only (from Florida). In view of these facts and in view of the paucity of published lists of Cuban algae, the list of algae of the Tomas Barrera Expedition, even though brief, seems to the writer to be worthy of publication. The list of algae embraces 65 named species and four species that are referred to genus only. In addition to the algae two species of *Halophila*, marine seed-plants representing a group that is commonly neglected by the collectors both of marine algae and of dry-land spermatophytes, are named. Both of these species appear to have been hitherto unreported for Cuba.

The principal and, it may be said, the only general treatise on the algae of Cuba, is that contributed by C. Montagne to Ramon de la

¹ 8 vo. Pp. i-ix + 1-320. G. P. Putnam's Sons, New York and London. 1916.

Sagra's "Histoire physique, politique et naturelle de l'île de Cuba" (1842. Spanish edition, 1845), in which 52 species of algae (excluding diatoms) are described or enumerated.

In 1871 Professor W. G. Farlow published a popular illustrated account of "Cuban Seaweeds" in *The American Naturalist* (5: 201-209). This was based upon specimens collected by Charles Wright and the author states that 46 species were identifiable. No general list, however, was published and the species mentioned and illustrated in the course of the popular discussion are all members of the order Siphonales of the Green Algae.

Two papers by M. G. de la Maza¹ on the Cuban flora include lists of algae based almost wholly upon the work of Montagne, and George Murray's "Catalogue of the Marine Algae of the West Indian Region"² includes references to Cuba based chiefly upon the papers of Montagne and of Farlow.

Dr. Otto E. Jennings,³ in a recent paper on the flora of the Isle of Pines, includes three named species of marine algae and three that are referred to genus only.

In the list, an asterisk is prefixed to the names of species that are believed to be attributed to Cuba for the first time. However, with changing conceptions as to specific limitations and with occasional uncertainties as to synonymy, it is not always possible to correlate accurately the nomenclature of the older lists with that here adopted.

CYANOPHYCEAE

Family OSCILLATORIACEAE

* *PHORMIDIUM HENDERSONII*, sp. nov.

Forming firm, cartilaginous, suborbicular or depressed-hemispheric, lubricous, bluish olivaceous or light green, often decolorate discs or cushions 2-7.5 cm. broad and 1-2.5 cm. thick, becoming corneous or corneous-coriaceous and only 1-3 mm. thick on drying, rather conspicuously lamellate, the lamellae (when fresh) mostly 300-600 μ thick, all except the youngest consisting chiefly of empty hyaline more or less confluent, though usually easily perceptible,

¹ Flora de Cuba. Tesis para el doctorado. Habana, 1887. Nociones de botánica sistemática. Habana, 1893.

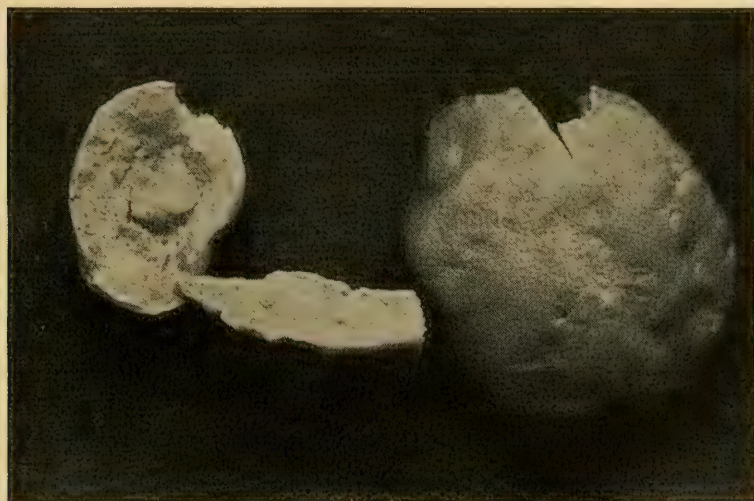
² Journ. Bot. **26**: 193-196, 303-307, 331-338, 358-363. 1888; **27**: 237-242, 257-262, 298-305. 1889.

³ A contribution to the botany of the Isle of Pines, Cuba, based upon the specimens of plants from that island contained in the Herbarium of the Carnegie Museum under date of October, 1916. Ann. Carnegie Mus. **11**: 19-290. pl. 5-28. 1917.

sheaths with occasional flexuous or contorted living filaments and inclusions of foreign algae and varied detritus; filaments of the superficial lamella crowded, usually flexuous or contorted, occasionally rather strict and suberect; vaginae close, mostly inconspicuous, not affected by chlor-zinc-iodine; trichomata pale olivaceous, $1.5-1.8\ \mu$ thick, not constricted at the septa, the apex straight, not attenuate; cells 2-6 times as long as broad, $3-9\ \mu$ long, the apical rounded, calyptra none.

On reef at Cayo Hutía,¹ Cuba, Tomas Barrera Expedition (*Henderson & Bartsch* 103, May 14, 1914). Types in herb. U. S. Nat. Museum and in herb. N. Y. Botanical Garden.

Phormidium Hendersonii is a close relative of the Hawaiian *Phormidium Crosbyanum* Tilden (Am. Alg. 645. 1909; Minnesota



Phormidium Hendersonii M. A. Howe. Photograph of formalin-preserved material, natural size. The right-hand figure shows the type-specimen from Cayo Hutia (*Henderson & Bartsch* 103), viewed from above; the left-hand figure shows a specimen from the mouth of Guánica Harbor, Porto Rico (*Howe* 6999), viewed from below; the middle figure shows a vertical section through a disc from Cayo Don Luis, Porto Rico (*Howe* 7192).

Alg. 96. pl. 4. f. 60, 61. 1910) but seems to differ in the more rigid-cartilaginous, more distinctly lamellate cushions, and the longer, less distinctly defined cells, which average about $5.6\ \mu$ long, while those of *P. Crosbyanum* average about $3.3\ \mu$ long. Being fleshy-cartilaginous and often decolorate, it is slightly suggestive of the base of a sea-anemone or other actinarian, and is probably sometimes neglected by the botanical collector as not pertaining to his field of action. The

¹ Often spelled "Jutias" on Cuban maps.

species is of rather common occurrence on the shores of the West Indian region, finding its best development on old coral slabs, rocks, etc., just below the low-tide mark in shallow warm water, in such places, in fact, as are most favored by *Dictyosphaeria favulosa*. Recent collections by the present writer in Porto Rico are his numbers 6998 and 6999 (mouth of Guánica Harbor, June 21, 1915), 7192 (Cayo Don Luis, June 27, 1915), and 7204 (Salinas Cove, June 27, 1915).

PHORMIDIUM sp.

Station 12, between Cabo de San Antonio and Punta del Cajón, in 2-12 fathoms, May 24, 358e.

CHLOROPHYCEAE

Family CLADOPHORACEAE

CLADOPHORA FULIGINOSA Kütz.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275 l; station 14, on reef in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426i.

Kützing's type of the species was from Havana. This alga, plus its apparently ever-present fungus endophyte, seems to be Harvey's *Blodgettia confervoides*, described from Key West, Florida.

CLADOPHORA sp.

Station 16, Cabañas, 529.

Family VALONIACEAE

* **VALONIA VENTRICOSA** J. Ag. "Sea Bottles"

In shallow water about the keys at *Esperanza*, 16b; on a reef flat between Cayo Hutía and the little key N. E. of Light, 31e; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275b; station 13, in 2 fathoms, on mud and gravel, *Esperanza*, between anchorage and entrance, June 2, 417e.

* **VALONIA MACROPHYSA** Kütz.

Station 5, Dimas Bay, May 17, 125c; station 8, Los Arroyos, May 20, 217b; station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238d; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275j.

DICTYOSPHAERIA FAVULOSA (Ag.) Decaisne

Station 3, in 2 fathoms, Cayo Arenas, May 12, 21; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275a; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306h; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 425e and 426d; Bahía Honda, June 7, 475c; station 16, Cabañas, 506f.

*** CHAMAEDORIS PENICULUM (Ell. & Soland.) Kuntze**

Chamaedoris annulata (Lamareck) Mont.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 358b.

*** MICRODICTYON CRASSUM J. Ag.**

On a reef flat between Cayo Hutía and the little key N. E. of Light, 31d; in 2-3 fathoms, station 10, Punta Colorada, 254a; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 425f and 426f.

ANADYOMENE STELLATA (Wulf.) Ag.

Station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238c; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275k.

Family **DASYCLADACEAE****DASYCLADUS VERMICULARIS (Scop.) Krasser**

Dasycladus clavaeformis (Roth) Ag.

On a reef flat between Cayo Hutía and the little key N. E. of Light, 31f; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306i; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426g; Bahía Honda, June 7, 475n; Cabañas, 506g.

*** BATOPHORA OERSTEDI OCCIDENTALIS (Harv.) M. A. Howe**

Dasycladus occidentalis Harv.

Botryophora occidentalis J. Ag.

Coccocladus occidentalis Cramer

Station 7, in 1-3 fathoms, Ensenada de Santa Rosa, 174b; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306j.

CYMOPOLIA BARBATA (L.) Lamour.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 358a.

ACETABULUM CRENULATUM (Lamour.) Kuntze

Acetabularia crenulata Lamour.

Station 7, in 1-3 fathoms, Ensenada de Santa Rosa, 174a; station 8, Los Arroyos, 217c; in 2-3 fathoms, Cayo Punta del Tolete, 238a.

Family CODIACEAE

***AVRAINVILLEA NIGRICANS Decaisne**

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275d; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426a.

***AVRAINVILLEA LEVIS M. A. Howe**

Station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426b.

A form with a fimbriate-margined flabellum.

***RHIPILIA TOMENTOSA Kütz.**

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275e; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426c.

***UDOTEA CONGLUTINATA (Ell. & Soland.) Lamour.**

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275f.

***UDOTEA CYATHIFORMIS Decaisne**

Station 8, Los Arroyos, May 20, 217f; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306g.

***UDOTEA WILSONI Gepp & Howe**

Station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, Esperanza, 417a.

Type from the Anguilla Isles, Salt Key Bank, Bahamas.

UDOTEA FLABELLUM (Ell. & Soland.) M. A. Howe

Udotea flabellata Lamour.

Bahia Honda, June 7, 475d.

PENICILLUS CAPITATUS Lamarck

On reef, off Cayo Hutía, May 14, 73d; station 8, Los Arroyos, May 20, 217d; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306f; station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, June 2, 417d.

***PENICILLUS PYRIFORMIS** A. & E. S. Gepp

On reef, off Cayo Hutía, May 14, 73e; station 5, Dimas Bay, May 17, 125a; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306e; station 16, Cabañas, 506e.

***PENICILLUS DUMETOSUS** (Lamour.) Decaisne

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306k.

RHIPOCEPHALUS PHOENIX (Ell. & Soland.) Kütz.

Station 3, in 2 fathoms, Cayo Arenas, May 12, 23a; station 5, Dimas Bay, May 17, 125b; station 8, Los Arroyos, May 20, 217a; station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238e.

RHIPOCEPHALUS OBLONGUS (Decaisne) Kütz.

Station 3, in 2 fathoms, Cayo Arenas, May 12, 23b.

***HALIMEDA TUNA** (Ell. & Soland.) Lamour.

Along the main shore and bayous opposite anchorage, Santa Lucia Bay, May 15, 110; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275c; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, 306b; station 14, in 2-3 fathoms, coral, sand, and rock bottom, June 2, 425c.

***HALIMEDA DISCOIDEA** Decaisne

Station 3, in 2 fathoms, Cayo Arenas, May 12, 22b; on reef, off Cayo Hutía, May 14, 73c; station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238b.

HALIMEDA TRIDENS (Ell. & Soland.) Lamour.

Halimeda incrassata (Ell. & Soland.) Lamour.

Station 3, in 2 fathoms, Cayo Arenas, May 12, 23c; on a reef flat between Cayo Hutía and the little key N. E. of Light, 31c; station 5, Dimas Bay, May 17, 124; station 7, in 1-3 fathoms, Ensenada de

Santa Rosa, 174c; station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306c; station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, Esperanza, June 2, 417b; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 426e; Bahía Honda, June 7, 475e; station 16, Cabañas, 506d and 506m.

* **HALIMEDA SIMULANS** M. A. Howe

Station 8, Los Arroyos, May 20, 217e; station 16, Cabañas, 506c.

* **HALIMEDA MONILE** (Ell. & Soland.) Lamour.

Station 7, in 1-3 fathoms, Ensenada de Santa Rosa, 174d; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 425d.

HALIMEDA OPUNTIA (L.) Lamour.

In shallow water about the keys at Esperanza, 16a; station 3, in 2 fathoms, Cayo Arenas, May 12, 22a; on reef, off Cayo Hutía, May 14, 73b; station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, Esperanza, June 2, 417c; station 16, Cabañas, 506b.

* **HALIMEDA LACRIMOSA** M. A. Howe

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 306d. The only known collection of this species outside of the Bahamas.

CODIUM TOMENTOSUM (Huds.) Stackh.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275g; station 16, Cabañas, 506a.

Family CAULERPACEAE

CAULERPA PROLIFERA (Forsk.) Lamour.

Station 5, Dimas Bay, May 17, 125d.

CAULERPA SERTULARIOIDES (S. G. Gmel.) M. A. Howe

Caulerpa plumaris (Forsk.) Ag.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275h.

CAULERPA CUPRESSOIDES (West) Ag.

Station 10, in 2-3 fathoms, Punta Colorada, 254b.

***CAULERPA PASPALOIDES (Bory) Grev.**

On reef, off Cayo Hutía, May 14, 73a; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275m.

***CAULERPA PASPALOIDES WURDEMANNI (Harv.) Web. v. Bosse**

Caulerpa Wurdemanni Harv.

Station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, Esperanza, June 2, 417f.

***CAULERPA RACEMOSA OCCIDENTALIS (J. Ag.) Børg.**

In 2-4 fathoms, Santa Lucia Bay, May 13, 149.

PHAEOPHYCEAE

Family FUCACEAE

TURBINARIA TURBINATA (L.) Kuntze

Turbinaria trialata Kütz.

On reef, off Cayo Hutía, May 14, 73f.

SARGASSUM NATANS (L.) Meyen

Sargassum bacciferum (Turn.) Ag.

Station 8, Los Arroyos, May 20, 216.

Family DICTYOTACEAE

***ZONARIA ZONALIS (Lamour.) M. A. Howe**

Zonaria lobata Ag.

Styopodium lobatum Kütz.

Bahia Honda, June 7, 475b.

ZONARIA VARIEGATA (Lamour.) Ag.

On a reef flat between Cayo Hutía and the little key N. E. of Light, 31b; on reef off Cayo Hutía, May 14, 73g; station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238f; station 11, Ensenada del Cajón, off Cabo de San Antonio, 275i; station 14, in 2-3 fathoms, on coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 425b and 426h.

NEUROCARPUS JUSTII (Lamour.) Kuntze*Dictyopteris Justii* Lamour.*Haliseris Justii* Ag.

On a reef between Cayo Hutía and the little key N. E. of Light, 31a; station 12, in 2-12 fathoms between Cabo de San Antonio and Punta del Cajón, May 24, 306a; station 14, in 2-3 fathoms, coral, sand, and rock bottom, on reef Lavesos Italianos, opposite Cayo Lavesos, June 2, 425a; station 16, Cabañas, 506h.

***DICTYOTA BARTAYRESII** Lamour.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 307b; station 16, Cabañas, 506i.

DICTYOTA DENTATA Lamour.

Bahia Honda, June 7, 475f.

RHODOPHYCEÆ

Family CHAETANGIACEAE

***GALAXAURA LAPIDESCENS** (Ell. & Soland.) Lamour.

Station 16, Cabañas, 506l. The plants currently referred to this species probably represent the tetrasporic phases of a species belonging in another section of the genus—the section *Eugalaxaura*.

***GALAXAURA SQUALIDA** Kjellm.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275n.

***GALAXAURA OBLONGATA** (Ell. & Soland.) Lamour.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 307a.

Family RHODOPHYLLIDACEAE

***WURDEMANNIA SETACEA** Harv.

Station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238h; station 11, Ensenada del Cajón, off Cabo de San Antonio, 267a.

Family SPHAEROCOCCACEAE

***GRACILARIA CONFEROIDES** (L.) Grev.

Bahia Honda, June 7, 475a.

HYPNEA MUSCIFORMIS (Wulf.) Lamour.

On a reef flat between Cayo Hutía and the little key N. E. of Light, 31g; station 16, Cabañas, 505.

Family RHODYMENIACEAE

***CORDYLECLADIA IRREGULARIS** Harv.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 267b.

Family DELESSERIACEAE

***SARCOMENIA FILAMENTOSA** M. A. Howe

Station 16, Cabañas, 528a.

The second collection of this species. The type was from Cape Florida.

Family RHODOMELACEAE

***LAURENCIA OBTUSA** (Huds.) Lamour.

Station 16, Cabañas, 562.

LAURENCIA INTRICATA Lamour.

Station 9, in 2-3 fathoms, Cayo Punta del Tolete, 238g.

***LAURENCIA POITEI** (Lamour.) M. A. Howe

Laurencia tuberculosa J. Ag.

Laurencia gemmifera Harv.

Laurencia mexicana Kütz.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275 o; station 13, in 2 fathoms, on mud and gravel, between anchorage and entrance, Esperanza, June 2, 417g.

LAURENCIA CORALLOPSIS (Mont.) M. A. Howe

Sphaerococcus corallopsis Mont.

Corallopsis Sagraeana Mont.

Laurencia cervicornis Harv.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 358d.

Montagne's type of this species was from the vicinity of Havana, where it was collected by Ramon de la Sagra. Harvey's type of *Laurencia cervicornis* was from Key West, Florida.

ACANTHOPHORA SPICIFERA (Vahl) Børg.*Acanthophora Thierii* Lamour.

Bahia Honda, June 7, 475g.

DIGENEA SIMPLEX (Wulf.) Ag.

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 275p.

*** DASYA RAMOSISSIMA Harv.**

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 358c.

Family CERAMIACEAE

SPYRIDIA FILAMENTOSA (Wulf.) Harv.

Bahia Honda, June 7, 475h; station 16, Cabañas, 506k.

Family SQUAMARIACEAE

*** PEYSSONNELIA RUBRA (Grev.) J. Ag.**

Bahia Honda, June 7, 475 o.

Small fragments (475k and 475 l) of two other species of this genus occur under the same general number.

Family CORALLINACEAE

*** LITHOTHAMNIUM FLORIDANUM Fosl. (?)**

Station 11, Ensenada del Cajón, off Cabo de San Antonio, 359.

LITHOPHYLLUM sp.

Bahia Honda, June 7, 475m—a fragment only.

*** GONIOLITHON STRICTUM Fosl.**

Bahia Honda, June 7, 479; station 16, Cabañas, 524.

Foslie's type was from Florida.

CORALLINA CUBENSIS (Mont.) Kütz.

Station 12, in 2-12 fathoms, between Cabo de San Antonio and Punta del Cajón, May 24, 307c; Bahia Honda, June 7, 475i; station 16, Cabañas, 506j.

* **AMPHIROA TRIBULUS** (Ell. & Soland.) Lamour.

On a reef flat between Cayo Hutía and the little key N. E. of Light, 31h.

SPERMATOPHYTA

Family ELODEACEAE

* **HALOPHILA BAILLONIS** Asch.

Bahia Honda, June 7, 475j.

* **HALOPHILA ENGELMANNII** Asch.

On reef, off Cayo Hutía, May 14, 73h.

SMITHSONIAN MISCELLANEOUS COLLECTION

VOLUME 68, NUMBER 12

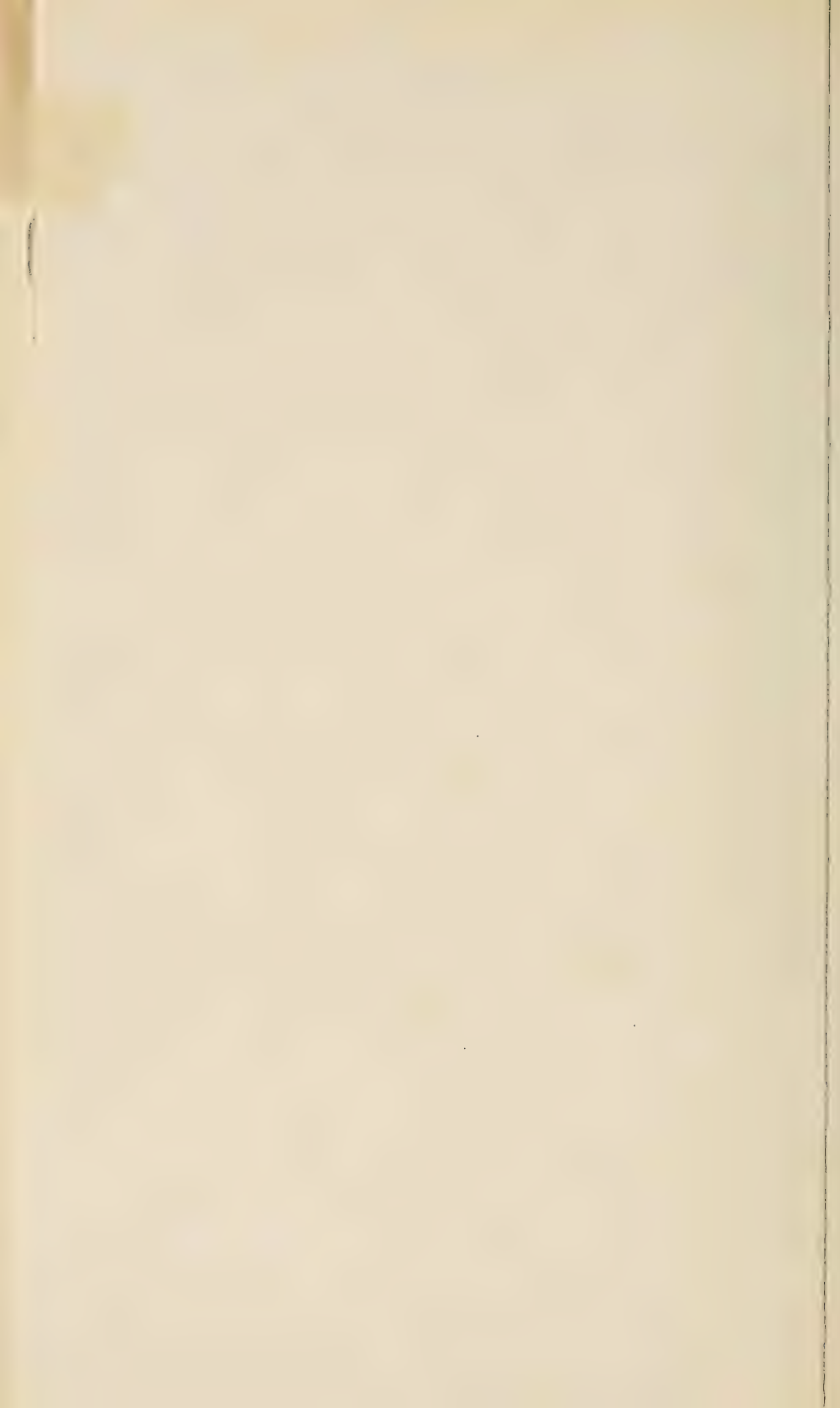
EXPLORATIONS AND FIELD-WORK OF THE
SMITHSONIAN INSTITUTION
IN 1917



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EXPLORATIONS AND FIELD-WORK OF THE SMITHSONIAN INSTITUTION IN 1917

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TUMBLING GLACIER AND CLIFFS (8,800 FT.)

MT. GRAY (9,200 FT.) NORTH TOWER (9,100 FT.)

BEAVERFOOT RANGE, WOLVERINE PASS (7,200 FT.)

MT. DRYSDALE (9,400 FT.)

WASHMAWAPTA WALL



FIG. 1.—Panoramic view looking west through Wolverine Pass, British Columbia, from a point 8 miles in direct line southwest of Vermilion P.

INTRODUCTION

A prominent department of activity throughout the history of the Smithsonian Institution has been the scientific exploration of regions imperfectly known, particularly in North America, although in recent years this work has extended to all parts of the world. These investigations have covered astronomy, anthropology, biology, geology, and in fact all branches of science. Besides extending our knowledge of nature and of man, there has been thus gathered and added to the National Museum collections an enormous mass of material of very great scientific interest and importance.

During the year 1917, the war greatly restricted the operations in foreign lands and the field-work was therefore largely limited to the United States. The accounts recorded herein have been written chiefly by those who have carried on the work.

Under the auspices of the Institution and in co-operation with the U. S. Geological Survey and other departments of the Government, there was carried on a few years ago a most thorough biological and geological survey of the Panama Canal Zone. The results of that important work are now being published in quite voluminous form. Among these publications now in press are "Contributions to the geology and paleontology of the Canal Zone, Panama, and geologically related areas in Central America and the West Indies" prepared under the direction of Thomas Wayland Vaughn, to appear as a National Museum Bulletin; also a comprehensive monograph on the "Mammals of Panama" by Edward A. Goldman. Numerous other works having to do with Smithsonian Explorations during recent years are enumerated in lists of publications issued by the Institution at regular intervals each year.

The geological field-work by Secretary Walcott in the Rocky Mountains during recent years has yielded important additions to our



FIG. 2.—Burgess shale fossil quarry blasted out on the steep slope of the ridge between Mount Wapta and Mount Field at 6,700 feet above sea level and 8 miles by trail from Field, British Columbia.

The fossil-bearing layers are just beneath the surface upon which the men are standing. Photograph by Walcott, 1914.

knowledge concerning the Cambrian and pre-Cambrian formations and has brought to light evidences of life far earlier than heretofore known. The results of much of this work in the field and subsequent

laboratory studies have been described in various Smithsonian publications. Likewise the ethnological researches herein briefly described will later be elaborated in the bulletins and reports of the Bureau of American Ethnology.



FIG. 3.—Undercutting by blasting in order to get at the fossil-bearing bed of rock in the famous Burgess Pass quarry. William Oke and Alex. Mitton drilling, while standing on poles high above the floor of the quarry. Photograph by Walcott, 1917.

GEOLOGICAL EXPLORATIONS IN THE CANADIAN ROCKIES

In continuation of geological work in the Canadian Rockies, Dr. Charles D. Walcott, Secretary of the Smithsonian Institution, was engaged during the summer and early fall of 1917 in field investigations and collecting at the now well-known "Burgess Pass fossil



FIG. 4.—Mrs. Walcott splitting out Middle Cambrian fossils from slabs of shale blasted out of the fossil-bearing bed of the Burgess Pass quarry. Photograph by Walcott, 1917.

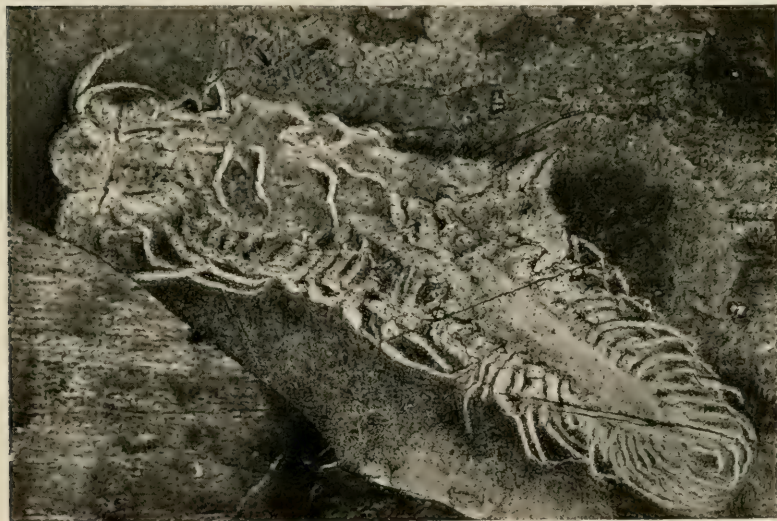


Fig. 5. ($\times 2$.) An elongate creeping holothurian (*Redoubtia polypodia*, new genus and species Walcott) with numerous tube feet and tentacles. This and the forms represented by Figs. 6 and 8 belong to undescribed genera and species and are here illustrated for the first time.

quarry," discovered by him in 1910. Fifty days were spent at the Burgess Pass camp, 3,000 feet above Field, British Columbia, where with the assistance of a miner and assistant, and packer Mitton, a section in the quarry of about 180 square feet was taken out. This practically exhausts a quarry which has given the finest and



FIG. 6.



FIG. 7.

FIGS. 6 and 7.—(About two-thirds natural size.) Another and larger holothurian with tube feet. (*Portalia mira*, new genus and species Walcott) that is finely preserved although crushed flat in the shale. An actinian (*Mackenzia costalis*) is lying on the posterior portion of the holothurian.

largest series of Middle Cambrian fossils yet discovered, and the finest invertebrate fossils yet found in any formation. More than one and a half tons of specimens were trimmed out at the quarry with the assistance of Mrs. Walcott and packer Mitton, wrapped in bundles carried by pack horses to camp and thence to the railroad



FIG. 8.—(About four-fifths natural size.) A large, beautifully preserved crustacean (*Helmetia expansa*, new genus and species Walcott) with a thin, semitransparent shell through which parts of the various appendages beneath the body may be seen. The two large eyes are finely shown on the rounded segment of the front of the head.

station at Field, and are now in Washington. Some of the undescribed forms are here illustrated by figures 5 to 8, and the operations of the quarry are shown by figures 2 to 4. Figure 2 shows the quarry just as the party left it in 1913, and figure 3 shows the back wall under which it was necessary to go to obtain fine pieces of the fossil-bearing rock. When the large slabs of hard shale are finally blasted loose they must be carefully split with chisel and hammer (fig. 4)



FIG. 9.—Mrs. Walcott giving Granny, the mountain squirrel, her noon-day lunch at the Burgess Pass fossil quarry. Photograph by Walcott, 1917.

to expose any fossil remains embedded between the laminæ of the compact, siliceous shale. The remarkable thing about the shale is that it preserves animals that were as soft and non-resistant as jelly-fish, worms, and the internal parts of worms and crablike animals. One of these is shown by figure 8. It is a swimming and crawling crab, seven inches long. It had two large eyes in front (shown by

the round white spots), six broad ribs, and a large tail. Branchiæ or gills shine through the thin shell as well as traces of the legs. Another curious form, figure 5, is a soft-bodied holothurian with many flexible podia or false legs. A small, round shell happened to rest on the sea bottom just where the head part of the animal was later pressed down upon it. Another soft-bodied form is *Portalia mira* (figs. 6 and 7), which is related to the sea cucumber or Holothurian which may be seen growing on the sea bed at Catalina Island, California. The shale bed at the quarry suggests that the waters of the acient Cambrian sea above it swarmed with life just as the ocean does to-day at Catalina Island. But this was long before the



FIG. 10.—Granny, the mountain squirrel. Frequently showers of broken rock and dirt were thrown by the blasting all about the place where Granny was sitting, but she invariably dodged under protecting slabs and appeared soon after as unconcerned as though nothing had happened. Photograph by Walcott, 1917.

advent of fishes on the earth so there were no fish, and no traces of them occur in the fossil bed. The superb preservation of the fossils at the quarry is all the more remarkable when we consider that they have been buried for twenty million years or more and subject to all the vicissitudes that rock materials experience from the time that they are simply hardened mud buried beneath thousands of feet in thickness of layers of mud, sand, and pebbles. Then all were changed by pressure and chemicalization into solid beds of sandstone, slaty shale, and limestone. These were later compressed and elevated into mountain ranges and more or less worn away by

atmospheric agencies. Beside the specimen of *Portalia mira* (fig. 7) there is an imprint of a mud-loving actinian (*Mackenzia costalis*) that closely resembles *Edwardsia*, a living form that usually lives buried in the sand.

"At the quarry," says Mr. Walcott, "we found one of our old friends that led me to write a note on animal behavior. When we were collecting fossils there in 1911, rock squirrels began to come to the quarry we were opening. At lunch time we threw them bits of



FIG. 11.—A summer snowstorm at Burgess Pass camp, 3,000 feet above Field, British Columbia, Canada. Photograph by Walcott, 1917.

bread and crackers, and later carried up nuts to give them. They became very tame, and when we returned the following year (1912) one of them, that we named Granny, because she apparently had two generations of young squirrels that came with her, would run up on our legs and shoulders, and if we did not promptly give her something to eat she would give a sharp chirp to call attention. One rainy day when crouched under a rubber blanket at lunch time, Granny came, and seeing a cake of chocolate lying on my knee made a grab for it, running up my arm and over my shoulder with it so as to jump

to the rocks behind. I made a dash for her, catching her by the end of the tail, which resulted in snapping off the tail about midway. The following year (1913) she was about again as usual, being easily recognized by her stub tail (fig. 10).

"We did not visit the quarry from 1913 until the latter part of July, 1917. Just after a blast had been fired, which was the signal to the squirrels that we were about to eat lunch, we saw two or three of them coming down from the cliffs above. A few minutes later, Granny suddenly appeared at the edge of the quarry. I called her,



FIG. 12.—One of the party who would insist on sleeping beneath the pine trees away from the tent, as seen on the morning of July 27 at Burgess Pass camp. Photograph by Walcott, 1917.

'Granny,' and whistled. She immediately ran across the floor of the quarry, jumped upon my foot and ran up my leg, finally sitting up and begging for something to eat as she had done the years before. There were three strange persons in the quarry, and she would not go near them for several days until she had the opportunity of getting acquainted. The striking feature of this incident is that this mountain squirrel should have remembered through a period of four years, and at once ran and jumped up on me as she had been accustomed to do in the years before.



FIG. 13.—Looking up the Bow River from our camp near the Banff-Windermere road bridge a mile west of Mount Castle on the Canadian Pacific Railroad. Photograph by Walcott, 1917.
The high mountain in the center is Mount Temple (11,626 feet), one of the most beautiful mountain masses between Paradise Valley and the Valley of the Ten Peaks.

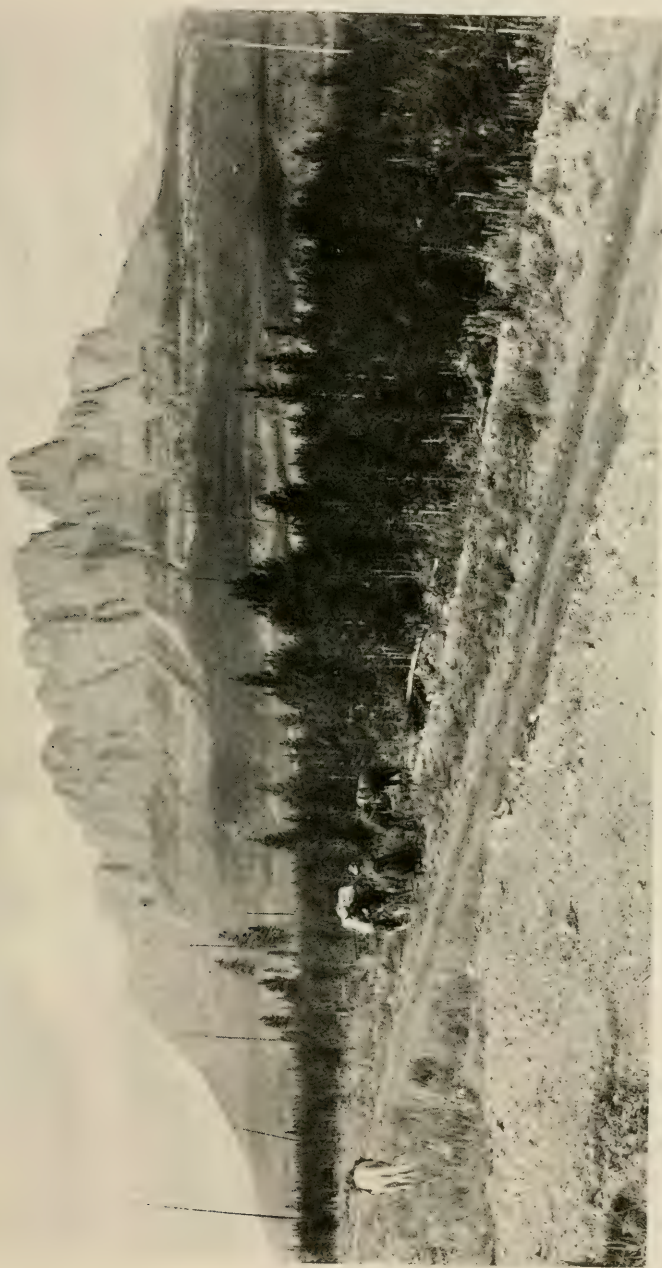


FIG. 14.—Castle Mountain, the citadel of the Bow Valley, 16 to 18 miles west-northwest of Banff, as seen from the Banff-Windermere automobile road below Vermilion Pass, Alberta, Canada. Photograph by Walcott, 1917.

"Four other squirrels came, two of which were evidently full grown and a year or more old, and two young ones. As Granny disciplined them all when they became too familiar, we supposed that they were members of her immediate family.

"After a week or more, Granny became very intimate with Mrs. Walcott and would jump into her lap and onto her shoulders, begging for food. She was entirely fearless, and would cling to a nut or a piece of chocolate and swing in the air until she secured the coveted bit (fig. 9).

"When the squirrels first came, they were very thin and extremely active. After a month of feeding, Granny became so stout that she had great difficulty in jumping from rock to rock. Chocolate, nuts, bread, and cookies seemed to agree with her, and the day we left the quarry a bountiful supply was placed under the rock ledges, so that they could all take the food to their nests, which were at the base of the cliffs, about 8,000 feet altitude.

"On July 27, a summer snowstorm buried the quarry, and at camp (figs. 11 and 12) it seemed more like November than July. Sunshine and a dry wind caused the snow to disappear within three days—leaving only very muddy trails and a cold, wet quarry.

"A few days were taken to verify a geologic section near Lake McArthur, and then the Vermilion River trip was begun. Following down the Bow River, we crossed it near Mount Castle and looked back towards Mount Temple (fig. 13). That night we camped at Vermilion Pass. Some conception of the mountain walls of the upper Vermilion canyon valley may be gained from the view of the west side of Storm Mountain (fig. 15). Lower down the valley on the eastern side near the mouth of Ochre Creek, Syncline Peak (fig. 16) shows remnants of the compression and folding that accompanied the uplift of the mountain massif now cut by erosion into hundreds of mountains, ridges and canyons. In the lower canyon of Tokumm Creek, near Vermilion River, the water passes over a fall into a huge pothole (fig. 17) and then into a narrow, deep canyon where it is often lost to sight in the deep shadows of the overhanging walls. In two places deep potholes were long ago worn in the bed of the stream and, when their enlarging lower portions met, the water poured through the opening and finally the original rim between them was left as a natural bridge above the stream. A very good view of this was secured (fig. 18) by a long time exposure from 60 feet above the water.



FIG. 15.—West face of Storm Mountain (10,309 feet) from the east slope of Mount Whympet, about 2.5 miles (4 km.) below Vermilion Pass. Note the great amphitheater or hanging valley on the right and left of the main summit. Photograph by Walcott, 1917.



FIG. 16.—The north face of Syncline Peak (elevation 8,622 feet), which rises above the broad flat at the junction of Ochre Creek and Vermilion River, 5.5 miles (8.8 km.) southwest of Vermilion Pass. Photograph by Walcott, 1917. The close faulting of the thin Middle Cambrian limestones is beautifully shown by the bare cliffs above timber line.



FIG. 17.—Tokumm Creek and falls at mouth of lower canyon, one-quarter mile above Vermilion River and 3.5 miles (5.6 km.) southwest of Vermilion Pass, British Columbia, Canada. Photograph by Walcott, 1917.

Tokumm River below the falls has worn a narrow, deep canyon, and in places the canyon walls are so close together and so irregular that the stream cannot be seen from above.



FIG. 18.—Looking down into Tokumm Creek canyon below the falls shown in fig. 12. As the result of the wearing of very deep and large potholes in the massive Cambrian limestones the extended lower portions of adjoining potholes have been united, leaving a natural bridge near their upper margin far above the rushing torrent below. Photograph by Walcott, 1917.

"From the Vermilion River the party followed a new forest ranger trail up Tumbling Brook to a small, beautiful glacier beneath the great, eastward facing cliffs of Gray Peak which is shown in the panoramic view (fig. 1 of this sketch), on the left of the pass between it and Mount Drysdale.

"Wolverine Pass is a broad, rolling area at about timber line. On its southwest slope the northeast branch of Moose Creek begins, on



FIG. 19.—Bull moose shot for the collections of the United States National Museum. Photograph by Walcott, 1917.

A cow and young were also obtained near by, all on the west side of the Vermilion River, about 9 miles below Vermilion Pass.

the north slope the head waters of Ochre Creek, and on the southeast the drainage is to Tumbling Creek, a branch of Ochre Creek. The views from the upper slopes northeast of the Pass are among the finest in the Canadian Rockies.

"Mount Drysdale, on the right, rises 2,200 feet above the Pass, and Mount Cambria, on the left, 1,800 feet, the altitude of the Pass being 7,200 feet. Tumbling Glacier, on the left of Mount Gray, is formed from the snows blown over Tumbling Cliffs from the westward. On

the right of Mount Drysdale the eastern side of the great Washmawapta snow field may be seen; in the distance through the Pass the dark Beaverfoot Range, and beyond it in the extreme background the snowy peaks of the gray Selkirk ranges.

"A late September storm drove us back from Wolverine Pass to the Vermilion River where below Ochre Creek a search was made for moose. By a lucky scout on September 30, Vernon Wood located a herd above the Vermilion River, and the next day a great bull (fig. 19), a cow and young were brought down under permit granted by Chief Game Warden Byron Williams of British Columbia.

"There is a fine mountain region between the Continental Divide and the upper Kootenay Valley of British Columbia that still awaits exploration by the geologist and photographer interested in grand views and great series of very old rocks that were formed in the earlier history of the continent."

GEOLOGICAL AND PALEONTOLOGICAL FIELDWORK

But little was accomplished by the National Museum divisions of Economic and Systematic Geology in the way of fieldwork during the season of 1917.

During the latter part of April and early part of May, 1917, Assistant Curator Wherry of the division of Mineralogy, while on private business in the west, was detailed to collect materials for the school duplicate series in sundry easily available localities. This resulted in the acquisition of the lots mentioned below:

Upward of 100 geodes from the well-known locality at Warsaw, Illinois; 100 specimens of wolframite in matrix, 200 pounds of pegmatite carrying cassiterite, and an equal amount of amblygonite, from the region about Keystone, South Dakota; about 150 specimens of zinc and lead minerals and 200 pounds of beautiful chert breccia from the new zinc district at Picher, Oklahoma; and some 300 pounds of hematite with coarse apatite inclusions from Iron Mountain, Missouri.

The division of Invertebrate Paleontology has been enabled to carry out a more extensive series of investigations and collecting trips. Doctor Bassler reports that in company with Assistant Curator Doctor C. E. Resser, he spent ten days in the Frederick and Hagerstown valleys of Maryland with the object of securing for the exhibition series large examples illustrating the various types of conglomerate. Two fine, large masses of the well-known Triassic limestone conglomerate were obtained with little difficulty, but equally

good examples of the siliceous variety were secured only after much hard labor, owing to the ready disintegration of the rock on exposure. Efforts were finally successful, however, and there was also secured a mass of the so-called "edgewise" conglomerate several feet in diameter, which will well illustrate the phenomenon of intraformational conglomerate described a number of years ago by Secretary Walcott. This last was obtained where the steeply dipping lower Ordovician beds outcropped in such a manner that the desired material could be blasted without fracturing. The mass obtained is shown at



FIG. 20.—Steeply dipping Lower Ordovician strata near Hagerstown, Md., composed of "edgewise" conglomerate. Photograph by Bassler.

A in figure 20. Figure 21, about one-sixth natural size, shows this peculiar structure and the reason for the name "edgewise" beds applied to these strata. All of such conglomerates are the result of ancient mud deposits of tidal flats becoming sun cracked when exposed to the air. The dried edges of the sun-cracked areas become tossed about by the wind and the fragments finally accumulate in layers which ultimately are hardened into rock-like conglomerate. Conglomerates usually indicate the base of a formation, but this particular kind may occur at any place within a formation, whence Mr. Walcott applied the specific name "intraformational" to them.

Following the geologic work in the Appalachian Valley in the early summer, Dr. Bassler proceeded to central Kentucky where he spent several weeks in explorations for suitable exhibition specimens covering the general subject of stratigraphic paleontology. It was especially desirable that such phenomena as stratification, the occurrence of fossils, and unconformities should be illustrated in the Museum, and especial efforts were made to secure specimens exhibiting these features. Much discrimination was necessary in the selection of these objects, as it was essential to obtain specimens of such size as to be appreciated by the public and still not too large for

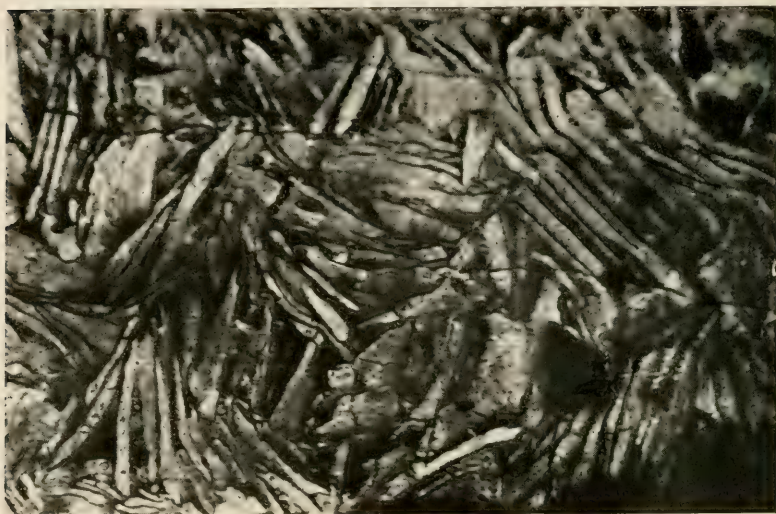


FIG. 21.—Surface of limestone layer A, of fig. 20, one-sixth natural size, showing "edgewise" conglomerate. Photograph by Bassler.

the available space, which is somewhat limited. This difficulty complicated the work, but the selection finally made was extremely satisfactory.

The early Paleozoic coral reef near Louisville, Kentucky, from which a section six by ten feet in dimensions had been quarried and placed on exhibition during the summer of 1916, was revisited and several additional layers of highly fossiliferous shale and limestone were secured. These have now been added in their proper position to the coral reef mount so that this single exhibit now illustrates the subjects of stratification in general, horizontal strata, change of lithology from limestone to shale, the occurrence of fossils in these

types of sediment, and the phenomenon of fossil coral reefs for which the exhibit was primarily planned.

The most valuable result of the summer's work was achieved at Elkins, Kentucky. Here a single limestone slab, six feet long and several feet wide and thick, showing an unconformity distinct enough to be appreciated by the layman, was quarried out and shipped to the Museum without breakage, where it now forms a most instructive



FIG. 22.—Unconformity between Early Black River limestone (white) and Early Trenton strata (dark) at Elkins, Ky. Photograph by Bassler.

exhibit. As shown in figure 22, the outcropping limestone ledge, several feet in thickness, is composed of a distinctly white lower portion and a dark-colored upper part, the head of the hammer marking their line of contact. This line also marks an unusually clear unconformity. Both of these layers are rich in fossils, those of Early Black River (Lowville) age occurring in the lower white rock and those of Early Trenton in the upper dark material. Since at other places in the United States five hundred or more feet of strata of Middle and Late Black River age intervene between these two layers, it is shown

that Kentucky was a land area during the deposition of the Middle and Upper Black River strata, and that the line AB therefore, marks an unconformity of deposition. This is also evidenced by numerous worm burrows extending downward from the top of the white limestone. When the material was in the condition of soft mud and exposed at the surface, the worms burrowed into it as they do in the soil to-day.



FIG. 23.—Phosphate mine of Wallace, Ky., showing occurrence of phosphate rock along joint planes of limestone. Photograph by Bassler.

The phosphate localities near Wallace, Kentucky, were next visited in order to obtain illustrations of the gradual phosphatization of limestone and the types of fossils in phosphatic strata. Here it was discovered that phosphate rock occurs only along the joint planes of the limestone, as shown in figure 23. Surface water passing along these joint planes leaches out the calcium carbonate of the phosphatic limestone, leaving the calcium phosphate content behind, as is well shown in the photograph. The piece of phosphatic limestone at C was removed and shipped to Washington for exhibition. Here also

another large mass of extremely fossiliferous phosphatic limestone was collected to illustrate the types of organisms composing phosphate rock.

In addition to the large exhibition material mentioned above, the geologic work in the Appalachian and Ohio valleys resulted in the securing of many hundreds of rock, mineral, and fossil specimens which were needed to complete certain of the Museum collections.

During the summers of 1916 and 1917, Mr. Frank Springer continued his researches upon the fossil echinoderms of the Ohio Valley with a view to obtaining further material and information for the completion of a monograph upon the Silurian crinoids of that area which he has now in preparation. His assistant, Dr. Herrick E. Wilson, collected in the vicinity of St. Paul and of Madison, in Indiana, proving for the first time the presence in the latter locality of the crinoidal faunas of both the Waldron and the Laurel formations. One object of the present field investigation is to obtain further light on the relations of the Silurian faunas of the Chicago and southern Indiana areas with those of western Tennessee. Mr. Springer acquired by purchase all the echinoderms in the large collection of Mr. John F. Hammell, of Madison, Indiana, which included that made by A. C. Benedict from the Indiana Silurian, containing the types of a considerable number of species. This material has been added to his collection of fossil echinoderms now deposited in the National Museum.

NORTH CAROLINA SOLAR RADIATION OBSERVATORY UNDER THE HODGKINS FUND

War conditions deferred an expedition which was proposed to be sent to Chile to observe the variability of the sun in co-operation with the Mount Wilson station of the Astrophysical Observatory. Preparations for the Chilean expedition had gone so far that the apparatus and supplies needful for several years were boxed for ocean shipment, and the observers, Messrs. A. F. Moore and L. H. Abbot, were engaged to leave for South America in May, 1917. It seemed, however, best to employ the outfit in the United States until a more favorable time should come to carry on observations in Chile.

Desiring to locate as far from Mount Wilson as practicable, so as to avoid simultaneous weather disturbances at the two stations, Director C. G. Abbot of the Astrophysical Observatory, after consideration of Weather Bureau records, fixed upon Hump Mountain in Avery County, North Carolina, as a high station, easy of access,

likely to give nearly 200 days per year favorable to solar radiation work. He went personally to the station, engaged the use of a plot of ground owned by Huff Bros. & Reynolds and the erection of two frame shelters thereon by a local contractor, W. H. Shores. The spot selected is at about 4,800 feet elevation, but at some distance below the top of the Hump, to avoid the tremendous winds which often prevent a strong man from standing on his feet. The houses were boarded within and without the joists, and the air space filled



FIG. 24.—Gorge at Hampton, Tenn., near Hump Mountain, N. C.

with shavings, to make them habitable in winter, for, notwithstanding the low latitude, the thermometer occasionally goes to -15° F. or even colder on the mountain.

The expedition went forward in May, 1917, and the apparatus was set up by Messrs. L. B. Aldrich and A. F. Moore. Observations were begun June 17. Director C. G. Abbot spent several days there early in July, instructing in the reduction of measurements.

Messrs. A. F. Moore and L. H. Abbot carried on the work until the close of 1917, and will continue it until the spring of 1918. The hope entertained for favorable weather has been disappointed.

Cloudiness was nearly continuous until October, and though no doubt this season was exceptionally bad, yet, even in the long stretch of fine weather of October and November, the values obtained were frequently ruined by changes of the atmospheric transparency. It is



FIG. 25.—Observatory and cook-house,
Hump Mountain, N. C.



FIG. 26.—L. H. Abbot observing
sky-radiation.

expected that results of special value will occasionally be obtained in the winter, owing to the low temperature and low humidity then prevailing, but there is no encouragement to continue the observatory for a term of years.

Valuable work has been done with the pyranometer on the brightness of the sky, the quantity of radiation available to vegetation in the forest, and on nocturnal radiation. This work will also go on through the winter, including measurements on snow fields, and the

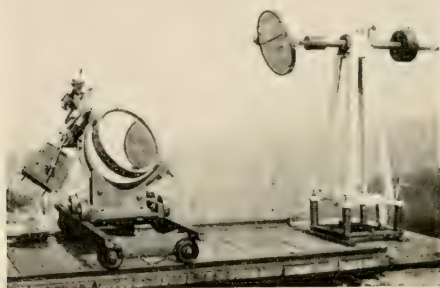


FIG. 27.—The coelostat for reflecting sun-rays.



FIG. 28.—A. F. Moore reducing observations with slide-rule machine.

investigation of certain errors likely to be made in nocturnal radiation work.

It is to be hoped that the expedition will yet be transferred to northern Chile. In that region where rain scarcely ever falls, winds never rise above the gentlest breezes, absolutely cloudless skies pre-

vail for 260 days per year, and skies not more than 1/10 cloudy prevail over 300 days per year, at an elevation above 8,000 feet, with sky of the deepest blue, the conditions are believed to be far the best in the world for the study of the variability of the sun.

It is now known that large fluctuations of the earth's temperature and of barometric pressure, changes of the intensity of terrestrial magnetism, variation of the numbers of sun spots and of the distribution of light over the sun's disk are all closely associated with variations of the intensity of solar radiation. Even our understanding of the variability of the stars is likely to be improved by the study of solar changes. All these and other probable applications of its results enhance the interest and value of the proposed Chilean expedition.

GRASSES OF THE ADIRONDACK AND WHITE MOUNTAINS

During the month of August, 1917, Mr. A. S. Hitchcock, systematic agrostologist in the Department of Agriculture and custodian of the section of grasses of the division of Plants in the U. S. National Museum, visited the Adirondacks in New York and the White Mountains in New Hampshire for the purpose of studying their flora, especially the grasses of the alpine summits. In the Adirondacks his headquarters were at Lake Placid from which point excursions were made to the summits of Whiteface and McIntyre, the highest peaks in the group with the exception of Mt. Marcy. It was impracticable to reach Mt. Marcy without the use of a camp outfit. This peak rises to a height of 5,344 feet but Mt. McIntyre is nearly as high (5,112 feet). Both McIntyre and Whiteface extend above the timber line and support at the summit an alpine flora.

The White Mountains reach a somewhat greater altitude than the Adirondacks, Mt. Washington, the highest peak, being 6,293 feet. In the Mt. Washington group there are several peaks whose summits are above the timber line. The alpine flora of these peaks and of the peaks of the Adirondacks are similar, and include plants that farther north are found at a lower altitude or, in the Arctic regions, even at sea level.

Four days were spent investigating the flora of the peaks. The ascent was commenced at Crystal Cascade on the east side, whence the trail led up Tuckerman Ravine to the summit of Mt. Washington, thence down to Lakes-of-the-Clouds where there is an Appalachian Mountain Club hut for the accommodation of climbers. From here the head of Oakes Gulf was explored. The second day was spent along the trail from Lakes-of-the-Clouds to the Mt. Madison hut,



FIG. 29.—Lake Placid, N. Y. A small lake with a portion of the town in the background among native pines and spruces.



FIG. 30.—In the Adirondack Mountains near Lake Placid, N. Y. Pasture in the foreground, meadow in the middle distance, young growth of spruce in the background, and forest in the distance. The forest is mainly made up of white pine and white spruce with a few larches.



FIG. 31.—In the Adirondack Mountains near Lake Placid, N. Y. White-face Mountain, the high peak in the background, is the third highest peak in the Adirondacks. The summit is above the timber line and supports an alpine flora.



FIG. 32.—In the Adirondack Mountains near Lake Placid, N. Y. The cone-shaped trees are white spruce. A thicket of alder borders the stream.



FIG. 33.—White spruce (*Picea canadensis*). Near Lake Placid, N. Y.



FIG. 34.—White pine (*Pinus strobus*). Lake Placid, N. Y.

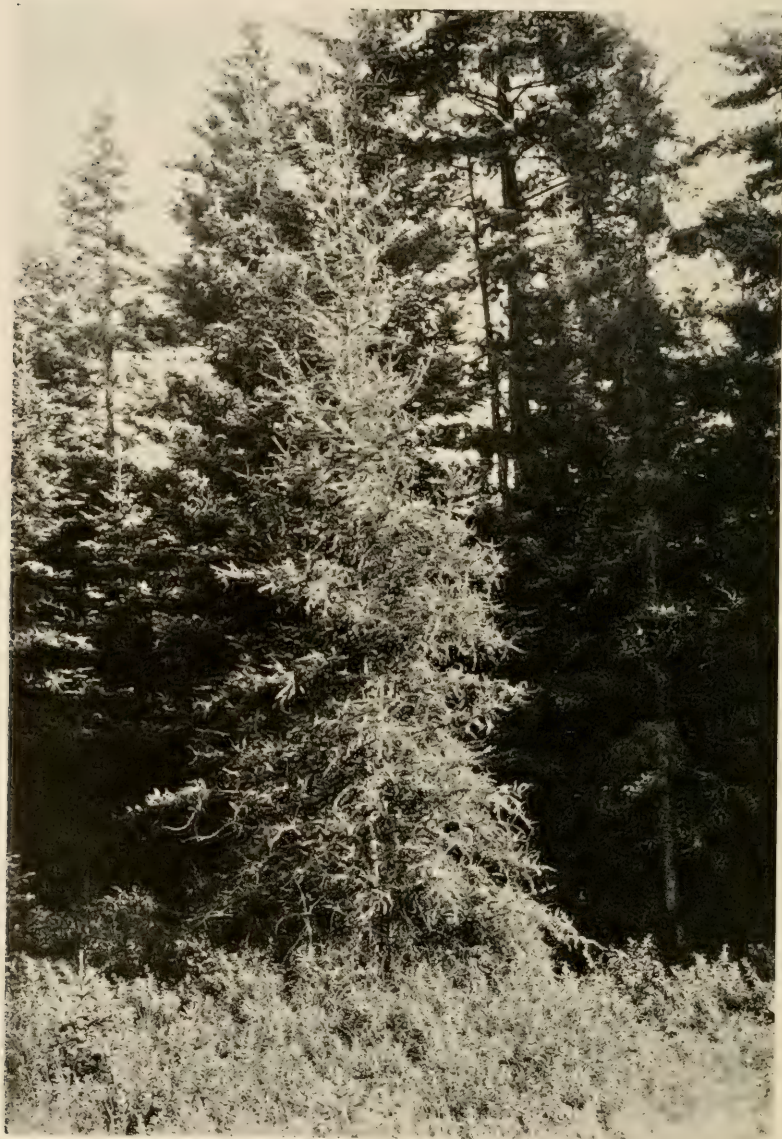


FIG. 35.—Larch (*Larix laricina*). Lake Placid, N. Y.



FIG. 36.—Lake Champlain at Plattsburg, N. Y. The marsh grass is the narrow-leaved wild rice (*Zizania aquatica*). The plants rise only a foot or two above the surface of the water. This species is distinctly smaller than the wide-leaved wild rice (*Z. palustris*) found so abundantly in the marshes around Washington.



FIG. 37.—The shore of Lake Champlain at Plattsburg, N. Y. The grass shown in Fig. 38 was found along the shore near here.



FIG. 38.—Wild rye (*Elymus canadensis*), growing along the shore of Lake Champlain near Plattsburg. This is the typical form as described by Linnaeus from specimens grown in his botanical garden at Upsala, the seed having been obtained from Kalm in Canada, possibly in the region of Lake Champlain.



FIG. 39.—White pine forest at the base of the White Mountains near Shelburne, N. H.

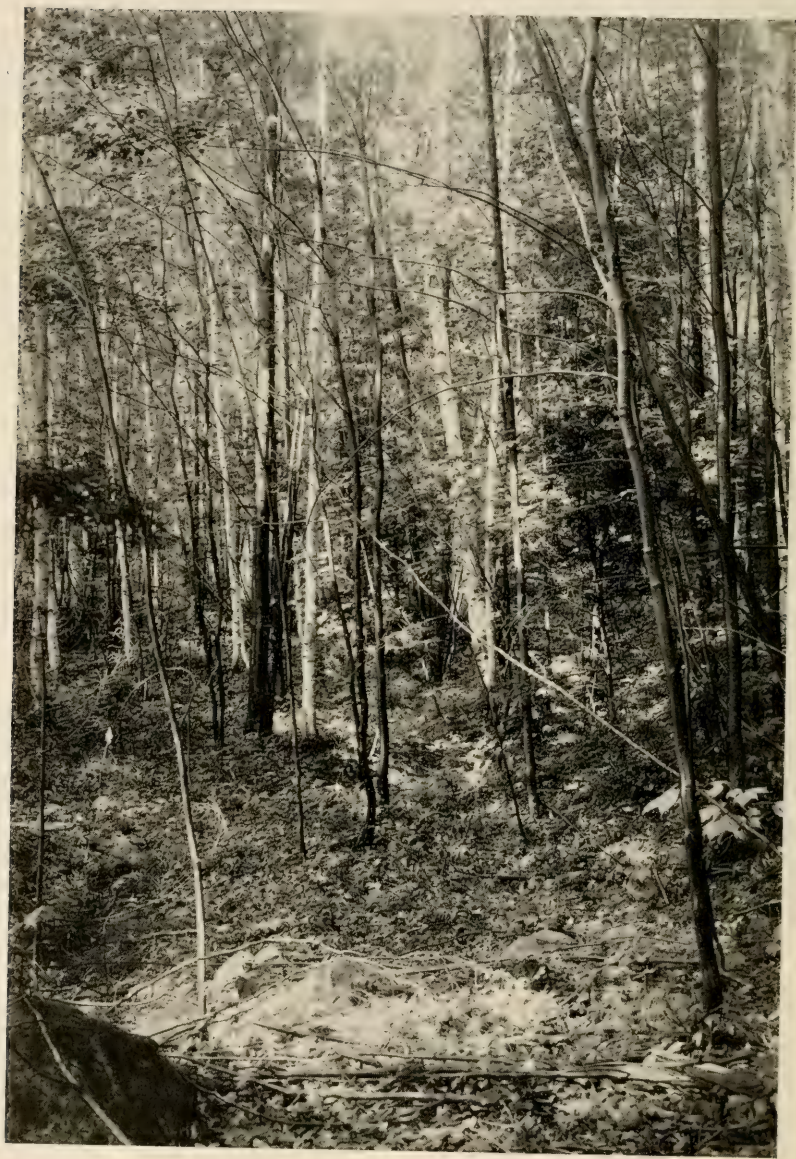


FIG. 40.—Dense forest, mixed deciduous and coniferous. At the base of the White Mountains near Shelburne, N. H.



FIG. 41.—Birch forest at the base of the White Mountains near Shelburne, N. H.

going by the way of the Westside and Gulfside trail, which passes near the high peaks of Clay, Jefferson, and Adams. The return trip to Lakes-of-the-Clouds hut was made on the third day, descending 3,000 feet through the Great Gulf by the Buttress trail and ascending again by the Six-Husbands trail to the Alpine Meadow. On the fourth day the descent was made by way of Huntington Ravine over a little used and difficult trail.

There are nine species of grasses that may be considered to be alpine. A few others extend from the lower zones into the alpine region. Most of the alpine species are circumpolar and extend southward in the mountains, one to the high peaks of western North Carolina, and two through the Rocky Mountains even to South America. One species, *Poa lava*, is abundant on the upper cone of Mt. Washington, extending quite to the summit, and comprises almost the only vegetation of this area. This is a European species which is found in North America only in the region of Mt. Washington and on a few of the higher peaks of New England.

The forest flora of the mountains consists mainly of white pine, white spruce, larch, aspen, and white birch. Toward the summits of the peaks the dominant tree is the balsam fir, which near timberline becomes a straggling shrub.

BIOLOGICAL EXPLORATIONS IN CUBA AND HAITI

In recent years Mr. John B. Henderson, a Regent of the Smithsonian Institution, has made numerous collecting trips to the West Indies usually accompanied by some members of the Museum staff, exploring new and little-known localities with special reference to the mollusk fauna.

In 1917, Mr. Henderson and Dr. Paul Bartsch, curator of the division of Marine Invertebrates, spent the month of March exploring the region about the Guantanamo Naval Station in eastern Cuba. This is a semi-arid coastal zone with a complex of hills differing faunally from the more elevated and humid Sierras of the interior. They subjected the region to a process of intensive collecting, securing a large quantity of very interesting land shells, birds, reptiles, plants, fossils, and marine invertebrates. Particularly fine series of the very interesting *Cepolis ovumreguli* and *Polymita versicolor* were secured, which are shown in the accompanying photographs.

Dr. Bartsch also made an exhaustive study of the ship worms (marine boring mollusks) of this region. A report thereon has been published in co-operation with the Corps of Civil Engineers, U. S. Navy.



FIG. 42.—A view on Lake Assuei: a habitat picture of the type locality of Henderson's Rail (*Porzana flaviventris hendersoni* Bartsch).



FIG. 43.—A yellow-billed tropic bird (*Phacton catcsbyi* Brandt) sailing from the nesting cliff a little west of Jeremie, Haiti.



FIG. 44.—The Haitian Palm Crow (*Corvus palmarum* Württemberg) seriously objecting to an examination of its nest, in the "Cul-de-Sac" region of Haiti.



FIG. 45.—A picture of the Haitian Burrowing Owl (*Spectyto floridana dominicensis* Cory) which, unlike its Floridian relative, is frequently seen in the trees.



FIG. 46.—The Haitian Lizard Cuckoo (*Saurothera dominicensis* Lafresnaye), an exceedingly important member of the Haitian avifauna.



FIG. 47.—Two Haitian lizards (*Ameiva chrysolacma* Cope), which rival the peacock in coloration. These are very abundant along the roadsides where, during the mango season, they feed very largely upon the pulp left clinging to the rejected seeds.



FIG. 48.—A plate of beautiful banded land shell (*Polymita versicolor* Born) from Guantanamo Bay, Cuba.

The month of April was spent in Haiti, where they thoroughly explored the "Cul-de-Sac" region, the north coast of the western peninsula and the coastal range from the "Cul-de-Sac" north as far as San Marc, from which regions very little land mollusk material was represented in the Museum collection. This material was very necessary in order to complete the links in the chain of the distribution of the West Indian land mollusks, a problem which presents many interesting scientific phases, which, when fully examined, will throw much light on zoogeographic distribution. In the "Cul-de-Sac," collecting stations were made about Port au Prince, along the line of the coast north of the city, at Thomazeau and on the shores of Lake Assuei. In the coastal range north of the "Cul-de-Sac," collections were made at numerous points from San Marc to Lake Assuei, the higher elevations being reached at Morne à Cabrits and the mountains back of Trou Caiman. Collections were also made in the hills south of Port au Prince and about Petionville.

On the north coast of the southern peninsula collecting was done at Petit Goave and Miragoane, but more concentrated efforts during a period of two weeks were devoted to the mountains about Jeremie, a region of considerable importance in the study of Antillean zoogeography. With Jeremie as a base, daily collecting excursions were made covering a very considerable area.

A representative series of about 15,000 specimens was secured; also about 1,000 other natural history specimens, including several new birds, some very interesting cacti and other plants and miscellaneous invertebrates, insects, fossil mollusks, fishes, batrachians, bats, and mice.

An extensive series of interesting photographs was also made, many of which will be used in a report on the expedition which the explorers hope to publish in the near future.

A VISIT TO THE CERION COLONIES IN FLORIDA

Through the co-operation of the Carnegie Institution and the U. S. National Museum, Dr. Paul Bartsch was enabled to again visit the Bahama Cerion colonies which he planted in 1912, for the purpose of studying the results attained during the past year. He reports securing a series of adult specimens of the second Florida grown generation which, when compared with those of the first Florida grown generation of the previous year's collections, will furnish the basis of a report showing the effect of the changed environment upon these organisms.

As in previous years, Dr. Bartsch kept a record of the birds observed between Miami and the Tortugas. These notes, as heretofore, have been published in the Year Book of the Carnegie Institution. An especially fine series of photographs of the birds inhabiting the Tortugas was secured and will furnish the basis for an article to be published in the near future in the Annual Report of the Smithsonian Institution.

ANTHROPOLOGICAL STUDIES ON OLD AMERICAN FAMILIES
BY ALEŠ HRDLÍČKA

In continuation of his researches on old American families, Doctor Hrdlička, in 1917, made trips to Yale, Virginia, and Harvard Universities. The last two were visited on the occasion of the "Teachers' Course" which brings to these institutions many adult individuals of old American parentage from a large territory. The work was greatly facilitated by the assistance received at Yale from Prof. George Grant MacCurdy; at the University of Virginia from Prof. Robert Bennett Bean; and at Harvard from Prof. K. G. T. Webster. The total number of subjects examined, mainly for pigmentation of hair, and eye and skin color, amounted to over one thousand, all of whom were Americans of at least three generations on both the paternal and maternal sides of the family.

The results which are now being elaborated for a report are of uncommon interest. They show a number of important facts of which we had no previous reliable knowledge. One of these is, in brief, that there is no increase in the proportion or grade of pigmentation as we proceed from New England southward, and no increase in blondness as we proceed northward from the Carolinas and Virginias. Another striking result shows that there are localized peculiarities in pigmentation, especially that of the hair, but that in every case these can be traced to the ancestry rather than to the environmental conditions. The latter nevertheless appear to have been active in general in reducing the total proportions of blondness.

So far as the color of the eyes is concerned there were found unexpectedly, in all the areas, a large proportion of "mixed" colors, in other words eyes in which more or less marked traces of brown co-exist with various shades of blue, green, or grey.

Three cases were encountered in which the color of the two eyes was markedly different. Pure, beautiful blues and browns were few in number.

THE MOUNTAINEERS OF TENNESSEE

During the latter part of July, Doctor Hrdlička made a trip to eastern Tennessee, for the purpose of becoming acquainted with the characteristics of the population of these regions, which in large part is of old American stock but has long existed under disadvantageous environment, remaining as a result backward in education and in other respects.



FIG. 49.—Samuel McQueen, 78 years old, mountains of eastern Tennessee.

The work commenced at Bristol, Tenn., extended to Mountain City, and farther on into the hills; and its success was very largely due to the kind offices and direct personal help of an old friend of the Smithsonian Institution, Mr. Samuel L. King of Bristol. For additional help the writer is indebted to Mr. John Caldwell of the same city.



FIG. 50.—Mr. J. H. Henderson, 83 years old, and his latest progeny, Silver Springs region, mountains of eastern Tennessee.

The work extended mainly to the men called for examination by the first draft for the U. S. Army and comprised 150 individuals. Both measurements and observations were taken. Some of the men came from the lower lands of the Bristol district and were kept apart, but a good number represented the real mountaineers.

It is too early to speak of the results of this interesting piece of research, the data not having as yet been properly reduced and



FIG. 51.—Mountaineers of eastern Tennessee. Mr. J. E. Morell, 54 y.; Mrs. M. Eller, 86 y.

analyzed; but it is safe to say that these mountaineers represent no separate type of Americans. In many cases they still show strong indications of their respective pre-American ancestry. Among the men there were seen some fine examples of physique—willowy, clean-cut six-footers; but there were also others of rather feeble mental powers or nervous stability, which conditions, to some extent possibly, are due to hereditary effects of alcoholism, or to defective heredity of other nature.

The families of the mountaineers are remarkable in many cases for their large size and there were seen examples of longevity and virility which it would be hard to find in our cities. One of the accompanying pictures shows the three younger children of Mr. Henderson, 83 years old. They are by his second (or third) wife and his children number 21 in all, a fair proportion of whom are still living.



FIG. 52.—E. Cornett, 24 years old, mountains of eastern Tennessee.

There are all grades of "mountaineers" and no line of demarkation separates them from the people in the lower lands, who are mostly of similar derivation and sometimes of the same families. But as one proceeds into the wilds of the mountains, the population becomes sparser and more backward, the cultivated patches of ground smaller in area, and the habitations poorer, until some of the latter come to resemble the shacks of the southern negro.

The poorer class of mountaineers frequently show characteristics partly due to their backwardness in education and their isolation, and partly perhaps to hook-worm disease or other abnormal conditions. Some of the young men are types of slouchiness, such as would delight the artist; while the women disfigure themselves by chewing snuff and frequently show uncouthness in dress, movements, and behavior. But the people are hospitable and interesting. In the course of a short ride of less than two miles through a sparsely settled gorge, the writer and his local companion had no



FIG. 53.—Mountaineer's shack and patch of corn, eastern Tennessee.

less than four invitations to lunch—in the other places there was no one at home. Their language and intonation are characteristic and quaint, and the people seem to be full of old and local folk-lore, the study of which would probably prove most delightful. Being largely dependent on themselves and their few neighbors they have also many antiquated and strange curative practices which would repay investigation.

Their worst enemies are the isolation, "moonshine" whiskey, and, in not a few cases, undoubtedly a poor heredity. The army draft

will be a God-send to many of the young men, some of whom can not even read or write; but probably few of those who will return will remain mountaineers.

THE VANISHING INDIAN

The progress of miscegenation among many of the Indian tribes has progressed to a degree that is surprising even to those who for



FIG. 54.—Ruth Spoon-Warrior, 73 y., full-blood Shawnee.

many years have been studying the Indian. While the total number of "Indians" as recorded by the census increases from decade to decade, the fact is that this increase is due wholly to that of mixed bloods; the full-bloods of pure strain are in most localities rapidly disappearing and in a considerable proportion of the tribes have become actually extinct or are on the point of extinction.



FIG. 55.—Nancy French (near 70 y.); John Scott (70 y. or slightly over), brother and sister, full-blood Shawnee.

Two remarkable examples of this fact have just been experienced by the writer. For years a growing necessity in American anthropology has been to determine the physical type of the Shawnee, once a large tribe and one of considerable historic importance. No great difficulty was apprehended in this task, as the tribe is still well represented. The most promising part of the tribe was that of the so-called "absentee" Shawnee, on the Shawnee Agency in eastern Oklahoma. They count 569 individuals, quite a few of whom are generally regarded as "full-bloods."



FIG. 56.—On the Shawnee Reservation. From left to right: Creek mixed-blood; Four-Dollars (82 y.), Shawnee with slight admixture of white blood; a half Shawnee half Delaware, with possibly some white blood.

Due to a grant of \$100 from the Committee of One Hundred on Research of the American Association for the Advancement of Science, the writer was able to visit the tribe during the early part of August, 1917. To his great disappointment the task of finding some pure-bloods became exceedingly difficult. Quite a few of the Indians were found to be "full-bloods," but on inquiry into the family history it was generally learned that the subject was a mixture of Shawnee with the Oneida, Delaware, Creeks, or some other tribe. In conclusion, there were found but three individuals

who so far as they or their friends knew were full-blood Shawnee. Two of these were old women and one an old man, all near or over 70 years of age, and two of the three were sister and brother.

The next tribe visited was the Kickapoo, the main body of which to the number of 211 is settled about McCloud, Oklahoma. They were said by the old Shawnee to be practically the same people with themselves, having at some time in the past had but one camp-fire, and it was generally believed that they would show some full-bloods of pure strain. This proved to be a vain hope. On close inquiry all sorts of mixtures were discovered, even among the oldest men and



FIG. 57.—On the Kickapoo Reservation. Children of mixed Indian blood.

women of the tribe, but no pure-bloods. Only one single woman of middle age was believed to be possibly a full Kickapoo, but there was no real certainty. Some visiting Kickapoo from Mexico proved no better than the rest, and no hope was given that any pure strain Kickapoo could be found anywhere else.

Thus two tribes, one of which of considerable importance, may be regarded as lost to science, so far as pure-bloods are concerned. Only a few years ago according to local information there were still a number of old men and women living in both tribes who represented the pure strain. The genuine Indian is rapidly passing away and the work of the anthropologist who endeavors to record the physical type of the various tribes is becoming increasingly difficult.



FIG. 58.—A Kickapoo child in a brush shelter.



FIG. 59.—On the Kickapoo Reservation. Young woman of mixed Indian blood.

EXCAVATIONS AT HAWIKUH, NEW MEXICO

An expedition was organized under the joint auspices of the Bureau of American Ethnology and the Museum of the American Indian, Heye Foundation, of New York City, for the purpose of conducting excavations at the ruined pueblo of Hawikuh, one of the celebrated Seven Cities of Cibola of the sixteenth century, occupied by ancestors of the present Zuñi Indians of western central New Mexico. This research, made possible by the generous aid of Harmon W. Hendricks, Esq., a trustee of the Museum of the Amer-



FIG. 60.—Looking east from Hawikuh across the Ojo Caliente plain. The elongate mound in the foreground is the ruin of the old church built about 1629. Photograph by E. F. Coffin.

ican Indian, was commenced in May, 1917, under the immediate direction of Mr. F. W. Hodge, ethnologist-in-charge of the Bureau, assisted by Mr. Alanson Skinner and Mr. E. F. Coffin of the Museum mentioned.

Both archeologically and historically Hawikuh is one of the most interesting Indian sites in the United States—from an archeological viewpoint by reason of the light the excavations are expected to shed on the primitive culture of the Zuñi people, and historically because of its prominent place in the earliest Spanish annals of the South-

west. It was the first of the Seven Cities of Cibola to be seen by the Franciscan Fray Marcos de Niza, the first white man to enter what is now New Mexico and Arizona, in 1539, and it was the scene of the murder of Estevanico, the negro guide of Fray Marcos. Coronado, who led the most remarkable expedition that ever entered the domain of the United States, stormed the town in 1540, captured it after almost losing his life in the effort, and wrote therefrom his celebrated letter to the Viceroy Mendoza on August 3, in which he set forth the progress of his army and described the customs and



FIG. 61.—The ruins of Hawikuh from the east. The summit of the knoll on which the pueblo was situated is sixty feet above the plain. Photograph by E. F. Coffin.

products of the natives. Hawikuh was visited also by Espejo in 1583, by Oñate in 1598 and 1604, and by other Spanish explorers. In 1629 a Franciscan mission was established there and an adobe church built (fig. 60), but in 1670 the pueblo was raided by the Apache and thenceforth abandoned.

The ruin of Hawikuh is situated on the summit and slopes of a mesa-like elevation (fig. 61), fifteen miles southwest of the present Zuñi pueblo; the entire area covered by the settlement approximates fifteen acres. Excavation was commenced in the western side of a great refuse-heap that covers the slopes, consisting of ashes and

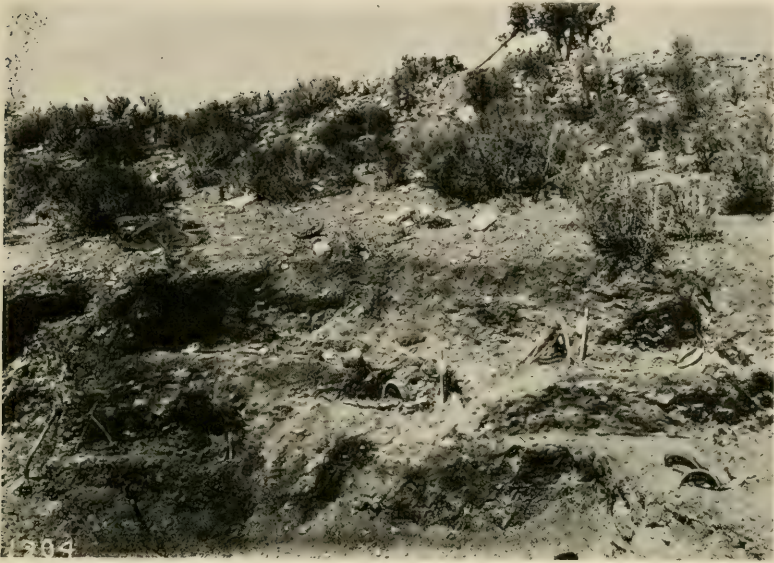


FIG. 62.—Several graves exposed in the Hawikuh cemetery.
Photograph by E. F. Coffin.



FIG. 63.—Uncovering the foundation walls of houses 15 feet beneath the refuse heap of Hawikuh. Ruined walls of the more recent pueblo are seen at the top. Photograph by E. F. Coffin.

other house refuse, the debris of building, sherds of pottery and other rejecta, and drifted sand. In this refuse the dead were buried (fig. 62). Beneath the deposit, at a depth of fifteen feet, the foundation walls of houses, built at two periods earlier than Hawikuh on the summit, were encountered (fig. 63) with burials of those who had occupied them, the graves being in the rooms, under the walls, and outside the houses, but rarely accompanied with pottery vessels or other artifacts such as were generally placed with the dead. The

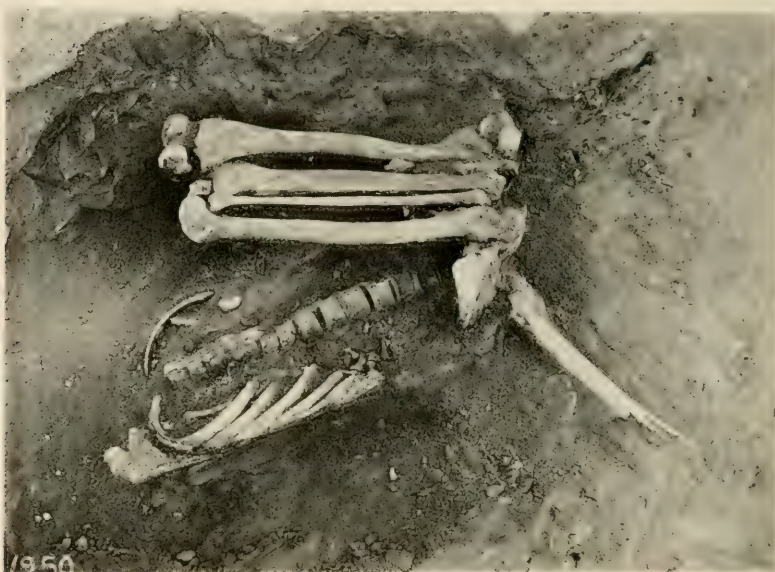


FIG. 64.—Remains of a partly dismembered burial found four feet deep in the refuse, without accompaniment. Photograph by E. F. Coffin.

skeletons in most of these older graves were usually incomplete, as if purposely dismembered at the time of burial (fig. 64); and in one instance the bones almost without exception had been deliberately broken (fig. 65). In addition to these two forms of burial the Zuñis of Hawikuh also cremated some of their dead and deposited the incinerated bones in jars, which were buried with the usual vessels of food and water. Evidently the personal ornaments of the dead were buried with the bodies in these instances, as calcined shell



FIG. 65.—A "pre-Hawikuh" burial almost every bone of which had been deliberately broken. Note the lack of burial accompaniments. Found 6 ft. 4 in. deep in refuse deposit. Photograph by E. F. Coffin.



FIG. 66.—Hawikuh. An extended burial with its accompaniments of pottery vessels, remains of loom beams and other weaving apparatus, fabrics, etc. Photograph by E. F. Coffin.

beads were found with the fragments of burned bones. Early Spanish writers speak of the Zuñi custom of cremating the dead. Above these interments, however, and extending to within a few inches of the surface, were the graves of the later people, those who lived in Hawikuh proper. These dead, unlike the more ancient



FIG. 67.—Hawikuh. The upper part of a skeleton almost completely covered with remains of baskets and corn. Note the prayer-sticks over the pelvis. Photograph by E. F. Coffin.

burials described, were interred usually with the head directed eastwardly, the body fully clothed, and accompanied with such personal belongings as, in the case of women, metates and manos, floor and hair brushes, head-rings used in carrying water jars, mats, baskets, raw material for various manufactures, together with pottery vessels

and quantities of food (corn, squash, piñon nuts, etc.), and articles of adornment such as hair combs and ear pendants of wood beautifully incrustated with turquoise and jet mosaic, shell and turquoise ear ornaments and necklaces, finger-rings, etc.; and in the case of men, bows and arrows, arrowpoints, fetishes, prayer-sticks, ceremonial paraphernalia of various kinds, pipes, and of course earthenware vessels and baskets that had contained food and drink. Examples of these more recent burials are illustrated in figures 66 to 68.



FIG. 68.—Hawikuh. Burial of an aged person, body greatly flexed, with a fine bowl decorated in glaze. Found $6\frac{1}{2}$ feet deep in refuse. Photograph by E. F. Coffin.

The pottery deposited with the dead of these burials consisted of from one to a dozen vessels of various forms and a wide range of decoration, although in some cases there were no such accompaniments at all. Bowls predominated, but there were many fine water jars, duck-shape vessels, and cooking pots of plain and indented ware. Most of the pottery utensils were sacrificed or "killed" by being thrown deliberately into the graves, and sometimes many stones were thrown in on them. The oldest decorated pottery from the site consists of a beautiful rich red or red-orange



FIG. 69.—A skeleton in a kneeling posture.
Photograph by E. F. Coffin.



FIG. 70.—Foundations of houses under the refuse of the western cemetery
of Hawikuh. Photograph by E. F. Coffin.



FIG. 71.—The remains of a grinding bin in a "pre-Hawikuh" house.
Photograph by E. F. Coffin.

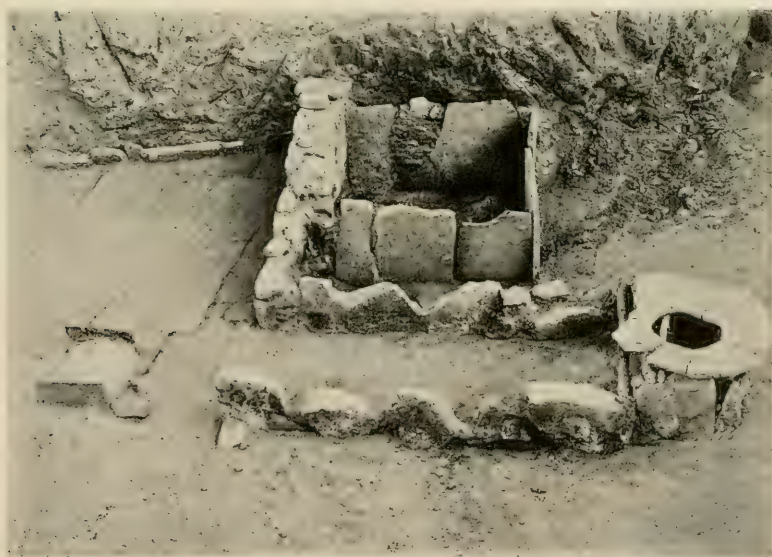


FIG. 72.—A curious structure at the bottom of the refuse, about 15 feet deep. The box-like enclosure, which was once roofed, was probably used for confining rattlesnakes. Photograph by E. F. Coffin.

ware on which was applied geometrical designs in black glaze. The more recent forms are decorated also in glaze, but in green, brown, and red, in addition to black, the glaze, however, was usually poorly applied. Effigy forms in relief are rare, but the eagle, weasel, butterfly, tadpole, and corn plant are among the non-geometric figures employed in ornamenting the vessels by painting. The baskets are chiefly of the woven type, but there is also an example of coiled basketry. Sometimes as many as four baskets were placed or thrown into a grave, almost completely covering the body (fig. 67). The



FIG. 73.—This rock *in situ* was used as a mortar and also for grinding manos and other tools. Photograph by E. F. Coffin.

fabric of the clothing was sufficiently well preserved for identification as cotton, which the Zuñis of Hawikuh probably obtained by trade from the Hopi, who were noted as cultivators of cotton in early times; indeed, early Spanish writers asserted that the people of Cibola did not raise cotton. The dead were often placed on or wrapped in mats, and frequently the grave was lined with cedar or juniper bast, which material served also for torches. Objects of Spanish provenience were encountered frequently—iron nails, a copper buckle, fragments of iron and copper, glass beads, bits of decorated porcelain, bottle-glass, and, at the neck of a child, a Catho-

lic medal or token. Near the floor of one of the houses, eight feet deep, was found half of a pair of scissors. Wooden objects were fairly well preserved, considering the length of time they had been buried, hence it was possible to save batten sticks for weaving, prayer-sticks, bows, arrows, war-clubs, ceremonial objects, loom frames (fig. 66), cane cigarettes, and the like.

Objects of bone are noteworthy because of the fact that so few were found in the graves as compared with the great number recovered from the refuse, no fewer than eighteen hundred being taken



FIG. 74.—The Zuñi workmen at Hawikuh. Photograph by E. F. Coffin.

therefrom. These consist of awls, gouges or chisels, needles, pins, whistles, beads of the tubular variety used both as necklaces and for wrist-guards, etc., and ranging from unfinished specimens through the simplest forms to more or less elaborately carved or incised examples.

The masonry of Hawikuh is of stone and is well constructed; indeed the walls are far superior to those of the houses found deep under the refuse (figs. 70 and 71), built before Hawikuh itself, or at least its western part, was erected on the great deposit of debris that covers these more ancient structures. The Zuñis raised turkeys, as was shown by the finding of the fragments of an egg-shell con-

taining the bones of the embryo, ceremonially buried with a food bowl, as well as bones of the adult fowl. Eagles were likewise ceremonially buried, and domesticated puppies were given place of interment with the human occupants of Hawikuh. A curious structure of stone slabs on the bottom of the refuse-heap was probably used for imprisoning rattlesnakes (fig. 72). Early Spanish writers mention such a custom at Hawikuh, and one of them states that the rattlesnakes were thus kept in order that their venom might be used for poisoning arrows.

A summary of all the interesting discoveries at Hawikuh is not possible in this brief space, nor is it desirable to offer conjectures respecting the significance of some of the features of the ruin or of various objects found in the course of the season's work, for much remains to be done before the task will approach completion. The excavations were brought to a close late in August and will be continued next season.

ANCIENT PIT DWELLINGS IN NEW MEXICO

Dr. Walter Hough, of the National Museum, spent the month of June, 1917, chiefly in continuation of an investigation on certain remains of ancient pit dwellings near Luna, New Mexico, mentioned in Smithsonian Miscellaneous Collections, Vol. 66, No. 17, 1916 (1917). Excavations were made in various parts of the area with the expectation of finding burials, accompanying skeletons and mortuary objects, but with small results. Sufficient information was secured, however, to give a fair knowledge of the structure of the houses and their arrangement into a village as shown in figure 75. This restoration is a summation of the data acquired through excavation and survey concerning the former aspect of the village. There is no evidence that the great dance pit was stockaded, but it is a reasonable presumption that this great pit, 84 feet in diameter and 10 feet deep, would require an enclosure. Dr. Hough is preparing a report on this interesting find. During the season another site containing about 15 acres was located about seven miles north of Luna, and it is probable that other sites may be found in the general region. The finding of ancient villages of this character is very difficult as they present few surface features by which they may be identified. Of these the shallow concave of a larger pit (dance or assembly pit) is generally the only evidence and this may be obliterated when the site was occupied subsequently by other tribes.

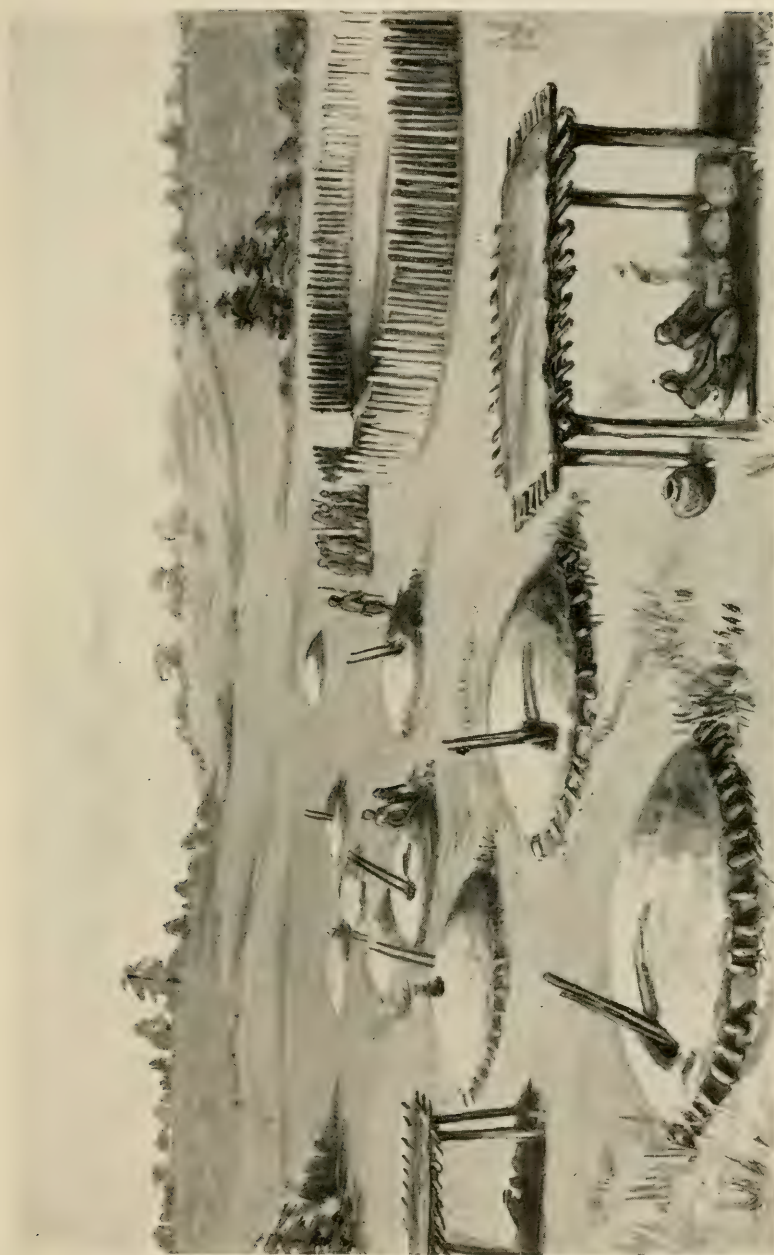


FIG. 75.—Restoration of Ancient Pit-village.

A walled kiva 54 feet square on a small stream running into the San Francisco River from the north was investigated and found to be of the type first discovered by Dr. Hough on the Blue River. On the wall of this kiva grows a huge pine fully matured. It seems rather strange that this kiva has not in its neighborhood any village ruins which would house a population commensurate with the importance of the work or efforts necessary to accomplish its construction.

In the course of the work a number of large ruins were located which appear to be worthy of further examination. The largest of these ruins are in the Fox, Escondido, and Gallo Mountains and seem to show that early migrations were conducted along the watered mountains which stretch eastward from the Escudilla mesa forming the southern boundary of a great arid basin area extending northward from the Rio Grande to the Arizona line. It was observed that the high mountain region presents a ruder culture than obtains at lower elevations in river valleys or basins on the slopes where agriculture produced better returns or where, in the flood plains of rivers having their source in mountains, irrigation is rendered feasible, as in southern Arizona. It was found also that the higher elevations in the mountains did not enforce a hunter life on the inhabitants for hardy varieties of maize could be raised, and thus the mountain culture of the Pueblos presents itself as a ruder phase of the more developed culture of the less elevated lands.

Dr. Hough investigated varieties of maize grown at 7,000, 7,600 and 8,000 feet at Luna, Eagar, and Alpine respectively, and secured samples for the Bureau of Plant Industry of the Department of Agriculture. He also collected a number of very interesting slab mask headdresses used in ceremonies by the White Mountain Apache Indians and other ethnological specimens from this tribe, together with some data on the puberty ceremony and so-called Devil Dance.

The masks, composed of elaborate structures of slats of agave flower stalk decorated with designs in colors and pendants of short rods, etc., are very difficult to obtain. They appear to be related to ceremonial paraphernalia which Dr. Hough obtained from caves in Arizona south of the White Mountain Apache Reservation, described in Bulletin 87, U. S. National Museum (1914).

ARCHEOLOGICAL WORK IN ARIZONA AND UTAH

The Indian Appropriation Act of May 18, 1916, provided \$3,000 for the excavation and repair of the prehistoric cliff-dwellings comprising Navaho National Monument in northern Arizona, the

work to be done under the supervision of the Smithsonian Institution. In March, 1917, Mr. Neil M. Judd, of the United States



FIG. 76.—The main group of dwellings at Betatakin as they appeared late in March. Mountain oak five inches in diameter grew on the debris in the middle portion of the cave.



FIG. 77.—Approximately the same view, after the work of excavation and repair. The long wall in the upper cave may be seen on the ledge above the walls in the middle of the picture.

National Museum, was detailed for this undertaking. He left immediately for Flagstaff, Arizona, engaged a small force of white



FIG. 78.—Restored walls and mealing room, on the sharply sloping cave floor at Betatakin. The original of the wall at the extreme right collapsed after a heavy fall of snow; the front wall of the house at the top fell during a particularly severe thunderstorm, while workmen were engaged below. The three parallel walls are restorations.

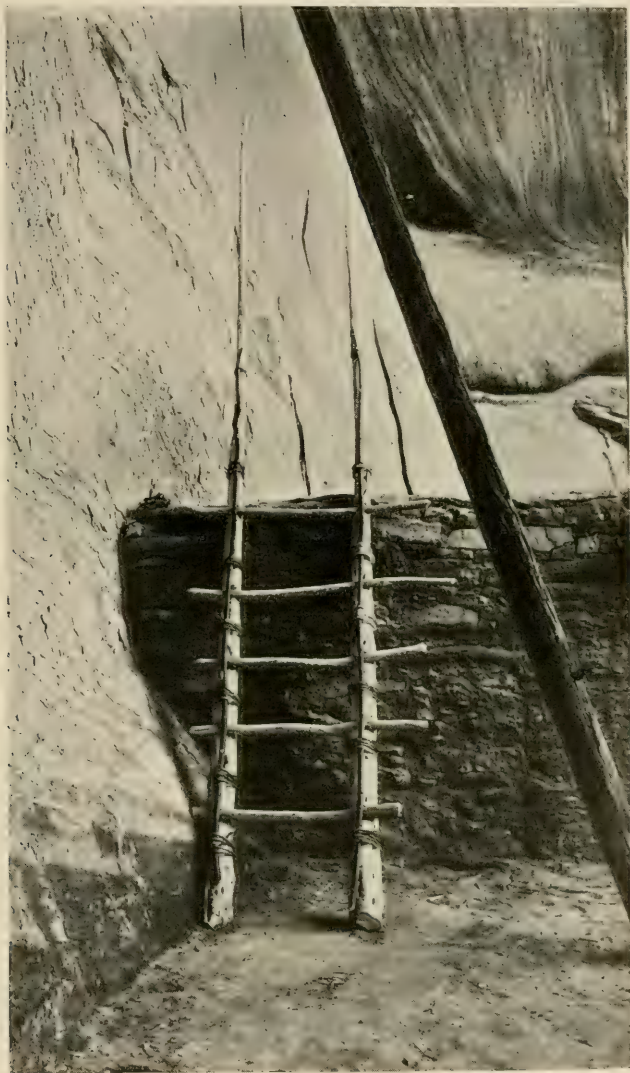


FIG. 79.—One of the ladders placed as a substitute for a series of steps, in this case, cut into the cliff at the left of the wall. The pole in the foreground was used by the ancients in reaching the upper cave from the main village.

laborers, and proceeded northward some 200 miles by trail to Betatakin ruin, an imposing structure which occupies a shallow cave in a branch of Sagie (Laguna) Canyon. Work was inaugurated at Betatakin in preference to one of the other two large pueblos within the boundaries of the monument chiefly for the following reasons: (1) More than one ruin could not be excavated and restored in the time available, from the sum appropriated; (2) Betatakin was, perhaps, in greatest need of repair; and (3) the site was more accessible than the others and furnished abundant water for camp purposes.

Extremely unusual and, oftentimes, discouraging conditions were experienced from the very beginning of the undertaking. Snow, rain, hail, and the severe wind and sand storms so common in the Marsh Pass region, followed each other incessantly, tending to delay and handicap the work in hand. In addition, greater difficulty than that anticipated was experienced in obtaining provisions and in engaging Indians either for work in the ruins or for transportation of supplies. Removal of the cave accumulations had been completed by mid-April, however, and the houses and retaining walls in greatest need of repair or restoration received proper attention before the expedition returned to Flagstaff, late in June.

The accompanying illustrations show the nature of some of the problems encountered at Betatakin and the methods adopted by Mr. Judd in meeting them. In restoring the ancient habitations, every effort was made to preserve the prehistoric atmosphere of the village. Mud mortar similar to that utilized by the original builders was employed in repairing their shattered dwellings and in replacing those house walls which had completely collapsed. In so far as possible, the sandstone blocks and weathered timbers uncovered during the course of the excavations were utilized in the structures as restored. Marks left by the tools of the recent party were carefully erased and imprints of the fingers were intentionally made in the newly laid mortar, the more completely to reproduce the handiwork of the aborigines. Unlike the ancient masonry, however, the new walls appear with joints carefully broken to insure greater strength and durability. The general appearance of the restored dwellings was so far above expectation that this slight distinction between the prehistoric walls and their modern counterparts will prove, in many instances at least, the chief means of distinguishing the latter.

A new trail was made across the talus below the cave, connecting with a series of rude steps which originally formed the principal entrance to the village. These and similar steps in other sections

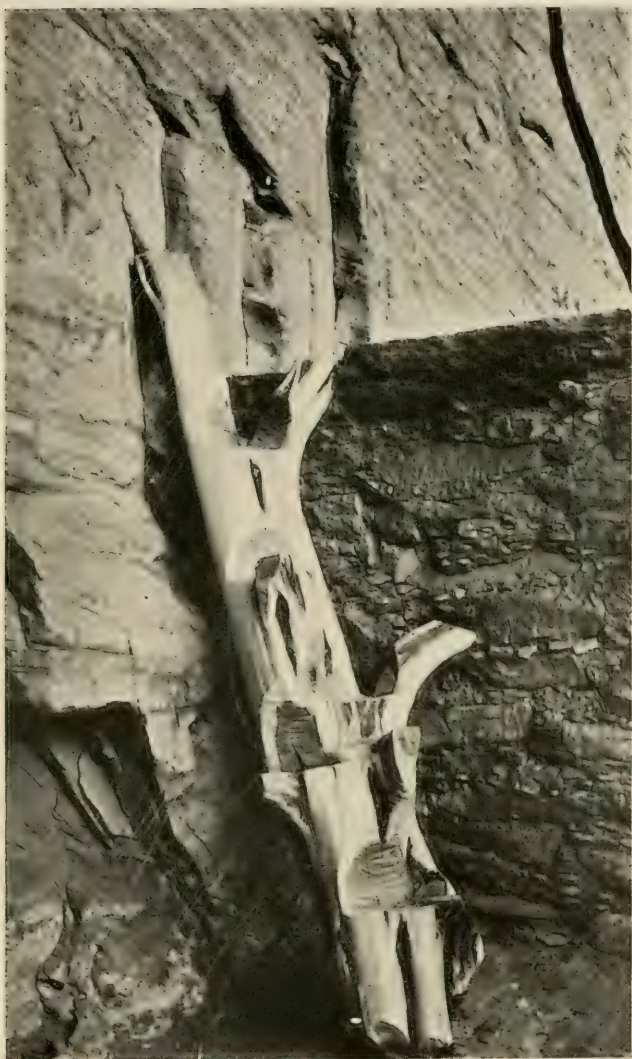


FIG. 80.—One of several ladders made from the notched trunks of cedar trees and placed in the open courts, as substitutes for series of shallow steps. Similar ladders are still in use among some of the modern pueblo villages of New Mexico and Arizona.

of the cave were enlarged and deepened to furnish secure footing for modern visitors. Ladders were provided as substitutes for steps in



FIG. 81.—Great masses of sandstone had fallen upon the houses at the eastern end of the cave, crushing their walls and oftentimes carrying them over the cliff below. Fragments of standing walls may be seen among the wreckage.



FIG. 82.—Approximately the same view, after the work of excavation and repair. Note the restored retaining wall in the middle foreground. It forms a walk or platform in front of a row of houses whose outer walls were of wattle construction.

other places, especially in open courts where ready access to neighboring housetops is still desired. As noted generally in prehistoric

dwellings of the Southwest, the house roofs at Betatakin were flat and furnished convenient workrooms as well as passages from one



FIG. 83.—A late April snow at Betatakin camp. Snowstorms were of almost weekly occurrence, from the beginning of the work until the last of May.



FIG. 84.—View from the central court, in the great ruin at Paragonah. In the foreground may be seen two fireplaces and charred fragments of three of the posts which supported the roof of a temporary shelter. At this point, seven distinct levels of occupancy were noted in six feet of court accumulations.

section of the pueblo to another. The new ladders, which form connecting links between the several courts, were made of the

notched trunks of cedar trees or from poles to which rundles were tied by willows and withes of squaw bush. Ladders of the second



FIG. 85.—In the foreground may be seen the walls of three superposed dwellings in the great mound at Paragonah. The ancient builders apparently leveled the walls of a house which had collapsed and, without removing the wreckage, built a new structure above the remains of the former.



FIG. 86.—The great mound at Paragonah, as viewed from the north, at the beginning of excavations.

type are frequently found in cliff-dwellings of the San Juan drainage and part of one was exposed by the recent excavations at Betatakin.

After concluding his work in Navaho National Monument, Mr. Judd proceeded to Salt Lake City, as field director of an archeological expedition organized jointly by the University of Utah and the Smithsonian Institution. Excavations were undertaken at Paragonah, in Iron County, where a mound approximately 200 feet square was razed to expose the ancient habitations it covered. The results obtained supplement the previous investigations of Mr. Judd in western Utah, as reported in earlier numbers of this series.¹ A large number of adobe dwellings, arranged in an irregular square, and three kivas or circular ceremonial rooms were uncovered and carefully studied. As observed during the two preceding years,



FIG. 87.—Approximately the same view as fig. 86, after the house walls had been exposed. The walls were made of adobe, built up in irregular layers; the roofs were of poles, covered with willows, grass, and mud. The flat, white areas represent different levels of occupancy.

numerous temporary shelters had been erected by the aborigines in the open courts between their houses; other similar huts were constructed at higher levels as the accumulations of the court increased in depth. An extensive collection of prehistoric artifacts, recovered during the course of the excavations, has been divided between the University of Utah and the Smithsonian Institution.

During his latest work in southwestern Utah, Mr. Judd was assisted by Mr. A. A. Kerr, as representative of the University.

¹ Smithsonian Misc. Coll., Vol. 66, No. 3, 1915, pp. 64-71; Vol. 66, No. 17, 1916, pp. 103-108.

TRIBAL RITES OF OSAGE INDIANS

In the month of January, 1917, Mr. Francis La Flesche of the Bureau of American Ethnology, visited the band of Osage Indians known by the members of the Osage tribe as the Paçiugthiⁿ, freely translated, "Those-who-dwelt-on-the-hilltop." Most of these Indians belong to that subdivision of the Hoⁿ'ga tribal division called Wazházhe, a name which the tribe as a whole bears to-day. For religious and ceremonial purposes the Osage tribe is divided into two great parts, one, the Tsi'zhu, representing the sky and the celestial bodies, and the other, the Hoⁿ'ga, representing the earth. The Hoⁿ'ga division is subdivided, one to represent the dry land, the other, called Wazházhe, the water (the seas, lakes and rivers). Each of these divisions and subdivisions has its own version of the great and complex tribal rites by which the people, from an unknown length of time, have been governed, and to which the older people still cling with the old-time reverence and superstitious awe, although these rites are now becoming disintegrated.

The visit of Mr. La Flesche to the "Hilltop" people was principally for the purpose of securing, if possible, a complete version of the tribal rites as practiced by the Wazházhe subdivision, or to secure whatever parts of these rites the members of the Wazházhe might be willing to give. Owing to the conservatism of the members of the Wazházhe subdivision no direct information could be obtained from them concerning their version of the tribal rites. When the men who are versed in the rites were approached on the subject, they simply remarked that the tribal rites are not to be discussed at all times and on every occasion, that the mysteries of the rites are only for those who are duly initiated, and then they become silent or take up for conversation a subject of everyday life. While these "Hilltop" people are consistent in their conservatism, as far as the rites themselves are concerned, they appear not to place as much importance upon the ceremonial paraphernalia, for they have disposed of many sacred objects to curio-hunters or to representatives of museums. The sale of a waxóbe (portable shrine, with its sacred hawk) resulted in a curious and pathetic incident. Five or six years ago a "Hilltop" man transferred his waxóbe (which is always equivalent to an offer of initiation into the tribal rites) to another member of his gens, but retained possession of it, although the transfer was formally accepted and the first fees were paid by the candidate. The keeper of the shrine, after waiting several years and not hearing further from his candidate, yielded to the persistent offers of a

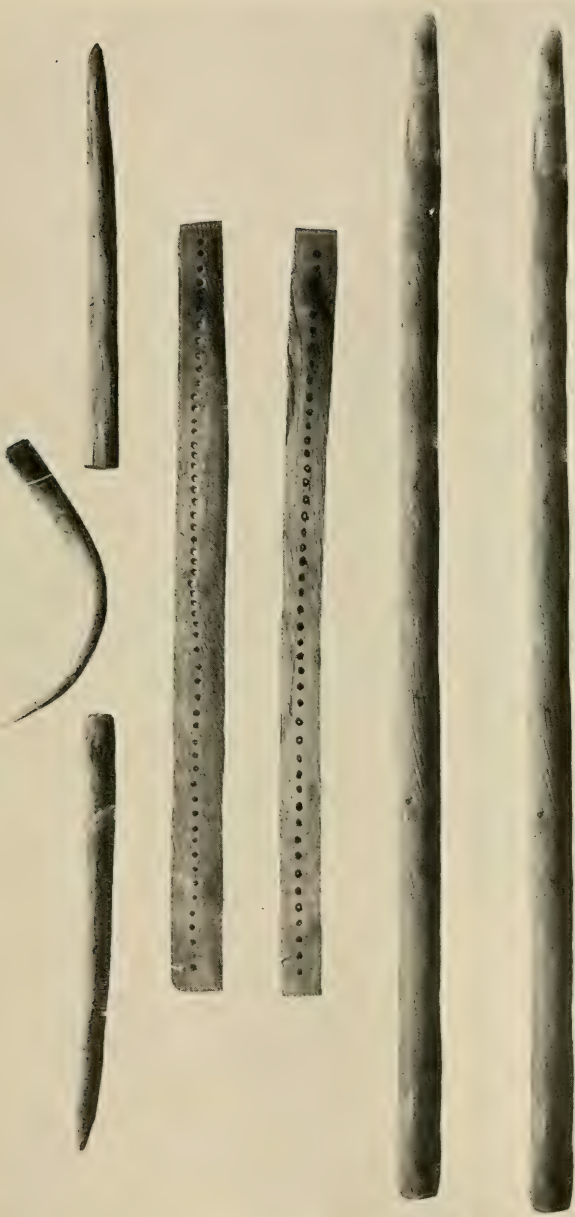


FIG. 88.—Stakes, perforated slats and deer's antler used for the loom and batten when weaving the rush mat and buffalo-hair covering required in making a portable shrine for the sacred hawk.

curio-hunter to purchase it and so parted with the shrine. About two years ago the candidate suddenly demanded that the initiation ceremonies be performed. The Noⁿ'hoⁿzhiⁿga, who had been duly summoned to witness the initiation, assembled, and the ceremonies proceeded in the prescribed manner, but without the waxóbe. At a certain part of the ritual a warrior who had won thirteen war-honors was called on to recount those honors to the sacred hawk in the presence of the assembled Noⁿ'hoⁿzhiⁿga. Kúzhiwatse, an aged warrior, and one of the remaining three in the tribe who could count the requisite number of war-honors at the ceremony, was chosen for this coveted honor. At the proper time the old man, gathering up in his hands the thirteen willow saplings which had been placed before him with which to count his honors, arose, thanked the members of the order for the honor conferred upon him, and then addressed the sacred hawk in the following manner: "O, Waxóbe, I rise to speak to you, in words that carry only the truth." Then, suddenly remembering that the waxóbe was not present, he added, "You are not here, but wherever you may be, perhaps in some place on the shores of yonder great water (pointing eastward), however long the distance may be, you will surely hear the words that I shall utter." Then, unmindful of the ill-concealed smiles of the Noⁿ'hoⁿzhiⁿga, he went on, with all the dignity of a warrior, to recount his war-honors, as though the sacred hawk, the emblem of the valor of the Osage warriors, was actually present in its accustomed place.

The results of Mr. La Flesche's efforts to secure from the members of the Wazháze subdivision, residing with the "Hilltop" band, their version of the tribal rites were disappointing. However, he took advantage of the opportunities that arose for securing other important information relating to the rites. One day there appeared at the Indian house where Mr. La Flesche was staying an old woman who said she had a set of "i'çagthe dapa" ("short-stakes") she wished to dispose of. I'çagthe dapa is the collective name of the stakes, perforated slats and deer's antler (see fig. 88), that are used as loom supports and batten in weaving the rush mats out of which are made the symbolic, portable shrines for the sacred hawks, war symbols, that are distributed among the various gentes of the tribe, and also for the weaving of the buffalo-hair bags that form the outer coverings for the shrines. The old woman said she felt that on account of her age she must soon be departing for the other world and she did not wish to leave the mysterious articles to her

children lest some harm befall them through neglect. She was told that a set had already been obtained from another woman, an official weaver, but that if she would give, with the loom, the wi'gie recited at the ceremonial weaving of the rush mat for the making of the shrine Mr. La Flesche would make the purchase. After some reflection the old woman said she was willing to give the wi'gie, but asked for time in order to refresh her memory.

In some mysterious way old Kúzhiwatse, though nearly stone deaf, heard that Wakoⁿ'dahioⁿbe was about to give away the

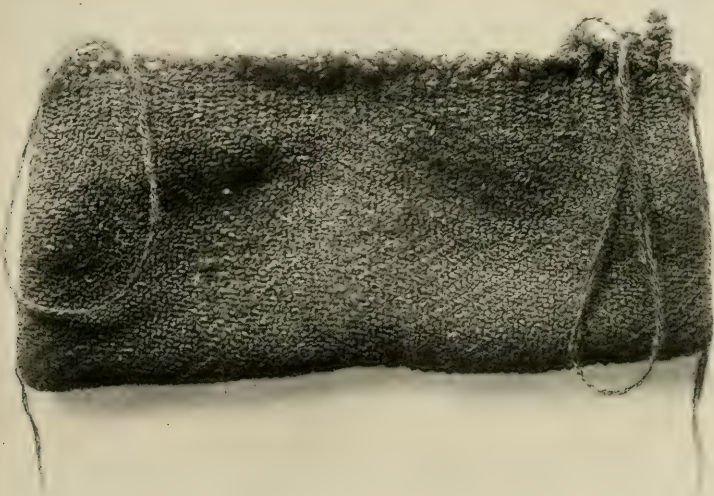


FIG. 89.—Buffalo-hair case that forms the outer covering of the shrine.

sacred loom and the wi'gie. He immediately got into an automobile, hastened to the old woman's house where he harangued her in vigorous manner on the sacrilege she was about to commit, and warned her of the Wáxpegthe. Wáxpegthe is punishment, by supernatural means, that constantly hangs over the head of a Noⁿ'hoⁿzhiⁿga and drops on the person the moment an irreverent act is committed. The old woman retorted that the Wáxpegthe applied only to the obligations assumed by a candidate for initiation; these obligations she had faithfully fulfilled, consequently she had nothing to fear. Kúzhiwatse then, assuming a conciliatory atti-

tude, told her that he would not object to her disposing of the sacred loom, but urged her not to give away the wi'gie, as that act would tend to hasten the disorganization of the Noⁿ'hoⁿzhiⁿga order. The old woman declared that she would dispose of both the loom and the wi'gie, claiming that they were hers by purchase, and emphasized her claim by enumerating to the old man the horses, blankets and other valuable articles she and her husband had paid as fees for her initiation.

Kúzhiwatse had assumed the right to interfere with the old woman's action because the wi'gie she had promised to recite belongs to the Wazházhe subdivision, of which he is a prominent member.

On the appointed day Mr. La Flesche appeared with his dictaphone at the old woman's house. Without hesitation she placed before him the "short-stakes" and told of Kúzhiwatse's action in the matter. Then, sitting on the floor in front of the machine, she dictated to it the ancient wi'gie, and sang the wailing song, doing this as though she was accustomed to the use of the dictaphone.

The wi'gie and the song she gave filled a gap in the detailed description given by Waxthi'zhi of the ceremonies that were connected with the ceremonial weaving of the portable shrine of the sacred hawk, a hiatus that Mr. La Flesche had almost despaired of filling, as his informant flatly refused to give the wi'gie, consistently adhering to the ancient rule that any part of the rites that exclusively belongs to one of the tribal divisions should not be used by any one belonging to the other divisions without first obtaining permission from the division having ownership.

The set of weaving implements obtained, as stated above, includes seven pieces: four stakes, two perforated slats, and a deer's antler. Two of the stakes are of the length required for the uprights of the loom when it is used to weave the rush mat to be used for making the shrine for the sacred hawk (see fig. 90). The other two are of the length needed as uprights for the loom when the buffalo-hair bag is to be woven (see fig. 89). All four stakes are pointed at one end so as to be planted in the ground and hold the loom steady. The two flat slats are perforated from end to end with small holes, through which are strung and fastened the warp of the piece to be woven. The slats are fastened at right angles to the stakes, one at the top and the other at the bottom, so as to hold taut the threads of the warp.

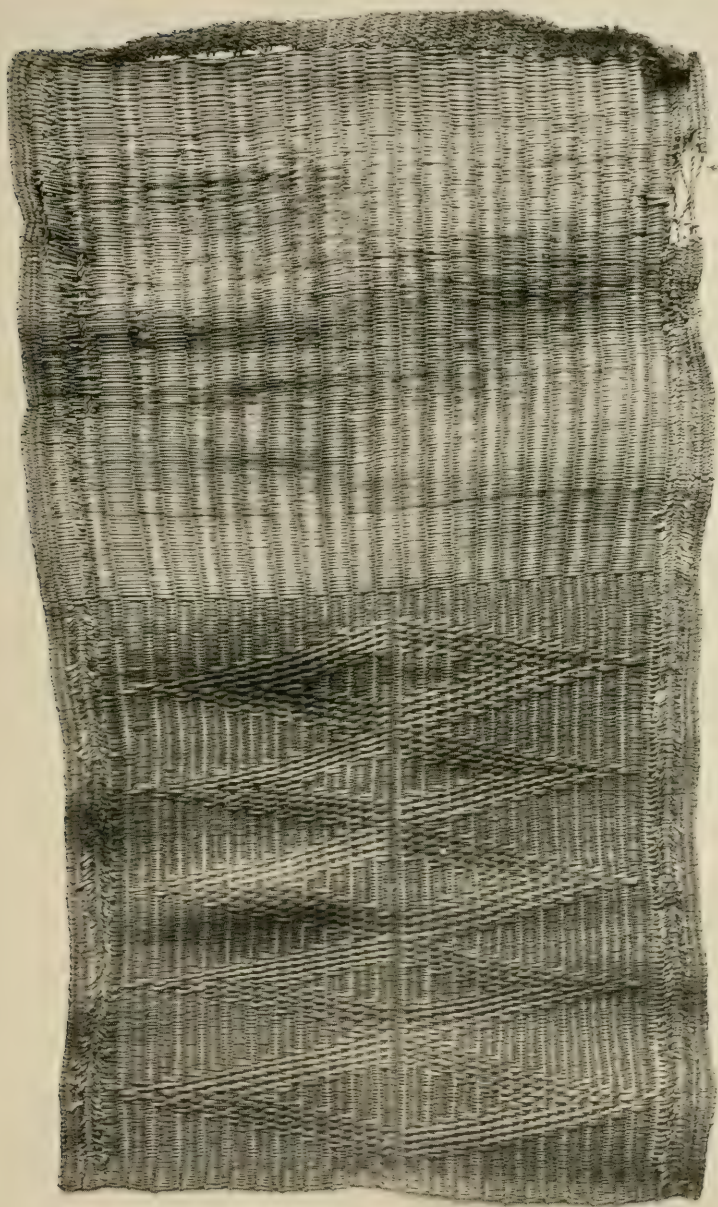


FIG. 90.—Rush mat, with its woven symbolic designs, which forms the portable shrine.

The loom and the batten, after having been ceremonially prepared and consecrated by the Noⁿhoⁿzhiⁿga for the weaving of the symbolic shrine of the sacred hawk, are believed to have become possessed of mythical power that could bring about not only the defeat of the enemies of the tribe, but punish by misfortune any individual member who might treat with irreverence these consecrated articles. The deer's antler used for a batten in the ceremonial weaving is believed to possess greater mystical power than the loom, because it not only symbolizes the sacred arrows of the Wazházhe subdivision, but also the arrows of all the warriors of the tribe.

STUDY OF THE FOX, SAUK AND POTAWATOMI INDIANS

Dr. Truman Michelson, of the Bureau of American Ethnology, left Washington on July 11, for field research among the Foxes near Tama, Iowa. Here he revised the texts pertaining to the White Buffalo Dance, obtained the esoteric meanings of the songs in these texts, and elucidated certain obscure passages. A part of the sociological work of the previous year was duplicated as a check. Lists of ceremonial organizations were made, and the names of the "officers" and the tribal dual divisions of these were secured. It was discovered that at least certain gentes have names for dogs and horses appropriate only to those belonging to members of given gentes; accordingly a number of such names was collected. A list of native terms of fishes and grubs was secured. A number of ceremonies (including the Snake Dance, which is rarely given, and some burials) were witnessed.

Near the close of September Dr. Michelson proceeded to the Missouri Sauks, who are partly in Kansas, partly in Nebraska. It soon became apparent that all who were worthy of ethnologic study had joined the Potawatomi in Kansas. Proceeding among the latter he spent a couple of days working with the Sauks, mainly on sociological matters. It appears that the regulations governing membership in the tribal dual division are not the same as among the Foxes of Iowa; nor are they apparently in absolute agreement with those of the Sauks of Oklahoma. Considering the brief stay with the Potawatomi, work was exceptionally successful. The phonetics of their language are rather complicated, some of the consonants at once recalling similar Delaware ones. A good beginning was made in regard to sociology, though details in many cases must be supplied later. It appears that the tribe is organized in exogamic groups with totemic names, with descent in the male line. The chieftainship

must be in the Bear gens. There were certain relationships of courtesy between gentes; the gentes had definite localizations in certain ceremonies, and had appropriate paints. The regulations regarding membership in the tribal dual division has not been definitely worked out, but it has become quite clear that the dual



FIG. 91.—Ida Poweshiek, mixed Potawatomi and Fox Indian girl of Tama, Iowa.

division was for ceremonial purposes as well as for the ball game. The names of the divisions show clearly that they have been derived from the Sauk, Fox, and Kickapoo. The system of consanguinity is clearly of the Ojibwa type, not that of the Sauk, Fox, and Kickapoo. A number of folk-tales and myths were collected, and it appears that

a fairly large number of European elements have been incorporated. The aboriginal matter definitely proves that two associations must be assumed—an older one with the Ojibwa group, and a later one with the Fox group. Certain plains and plateau elements also occur. The medium or media through which the latter came is as yet unknown. Dr. Michelson returned to Washington October 5.



FIG. 92.—An old Potawatomi man of Kansas.



FIG. 93.—An old Potawatomi woman of Kansas.

STUDIES AMONG THE INDIANS OF CALIFORNIA

Mr. J. P. Harrington, of the Bureau of American Ethnology, spent the period from January 1 to September 30, 1917, in continuing his California studies in the Santa Barbara region of southern California, amassing a large amount of valuable linguistic and other information. Mr. Harrington's time was divided between the Ventureño, Yneseño, Barbareño, and Purismeño dialects, most minute study

being devoted to the Ventureño. A considerably larger amount of the extinct Purismeño was rescued than it had been Mr. Harrington's good fortune to obtain on previous visits. Nearly all of the work was conducted with survivors of the older generation, but



FIG. 94.—Ventura Indian woman.

with the knowledge of this field which Mr. Harrington has acquired it was found possible to secure quite valuable information from some of the younger men, although this information requires to be weighed most carefully. Work in this field requires a thorough

knowledge of Spanish as well as of Indian culture, the two being strangely blent in the informants.

By carefully studying the archeological objects which have been found in the region, it has been possible to obtain an adequate idea



FIG. 95.—Old method of measuring bead money on hand.

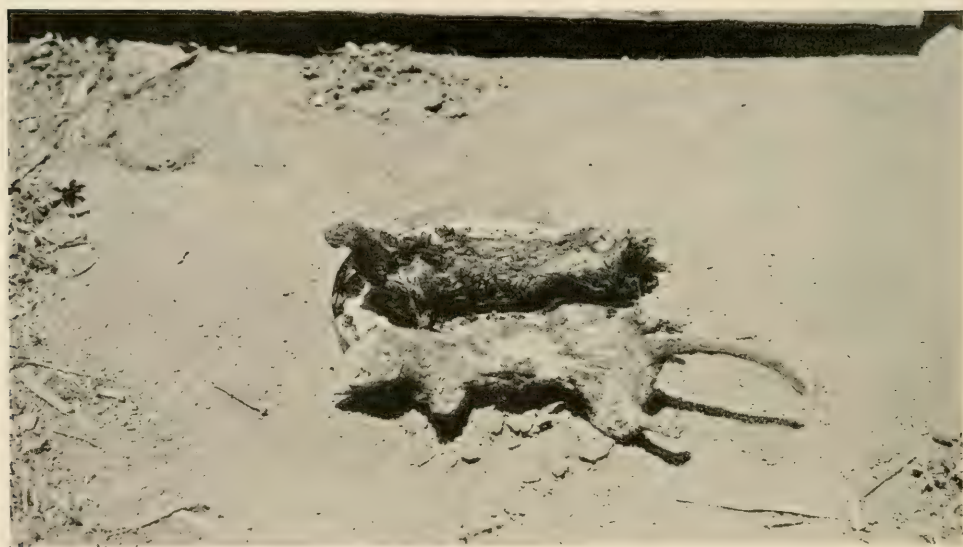


FIG. 96.—California ground squirrels roasted in ashes. One of the few ancient Indian foods which are still popular.

of many of the articles of the vanished material culture. In this way satisfactory information has been obtained on the subjects of personal adornment, archery, basketry, bags, beads and shell money, boats, brushes, buildings, clothing, cradles, deer-headaddresses, dolls, fishing,

food gathering and processes of preparation, hairdressing, mats, measures, musical instruments, regalia, string-making, tobacco and its uses, tools, traps, and other interesting points, although in some cases the informants had never seen the article.

Fortunately it is frequently possible to obtain ethnological information by a more direct method. An old woman was found who still remembered how to measure bead money on the hand, as illustrated by the accompanying photograph (fig. 95), and it is interesting to find Americanized descendants roasting California ground squirrels by the unaltered process of their ancestors (fig. 96).

At the end of September Mr. Harrington returned from the field.

STUDY OF CHIPPEWA MATERIAL CULTURE

During the summer of 1917 Miss Frances Densmore resumed a study of Chippewa material culture begun by her several years ago. This was made possible by the fact that considerable phonographic material had been collected and awaited musical analysis during the coming winter. Returning to the White Earth Reservation, Miss Densmore enlisted the co-operation of many Indians who had assisted in the study of Chippewa music, previously conducted in that locality. The Chippewa tribe has advanced in civilization beyond many other tribes, but there are individuals who neither speak nor understand English and who continue many of the old customs. From such informants a general outline of the old economic life was obtained and several branches were given intensive study.

The ethnobotany of the Chippewa was the subject of special investigation, and an ethnobotanical collection of about 200 plants was obtained, including plants used as medicines, food, dyes, and charms, as well as those used for general utility. With the medicinal plants were collected examples of surgical and medical appliances, and of substances other than vegetal used in remedies. The native names of plants were recorded, together with the portion and amount of a plant used in a remedy, the dosage, the treatment which accompanied its use, and the symptoms for which the remedy was prescribed. The investigation concerned chiefly the use of specifics, but a few combinations of herbs were recorded for comparison with the separate uses of the same herbs. Long life was the greatest desire of the Chippewa, and the attaining of long life formed the principal teaching of the *Mide* or native religion. Two factors were said to contribute to that end, namely, uprightness of life and the

proper use of medicines. Thus the efficient use of herbs was an important province of the *Midewiwin*, or Grand Medicine Society, and the secrets of these herbs were transmitted from one generation



FIG. 97.—Boat in rice-field. Photograph by Miss Densmore.



FIG. 98.—Parching wild rice. Photograph by Miss Densmore.

to another. Miss Densmore's former study of the *Midewiwin* contributed to the present research, as persons who recorded *Mide* songs more than ten years ago were willing to impart information concerning the herbs used in *Mide* remedies.

Food and its preparation formed the interesting subject of an inquiry, which was limited to the period preceding the baking of bread. The principal articles of food at that time were cooked rice and vegetables, fish, meat and game, berries, maple sugar, and beverages made from leaves and twigs. Wooden spoons, bone knives, and a "marrow stick" for scooping marrow from a bone were used within the memory of the older informants, and water was boiled in a vessel made of freshly cut birchbark if a trader's kettle was not available. The manner of securing each class of food was studied. Three rice-camps were visited and photographed, the process including the gathering of the rice, its parching, pounding,

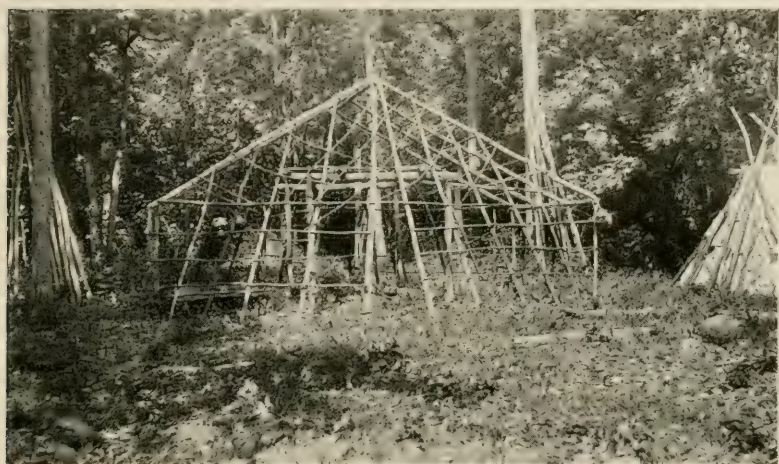


FIG. 99.—Frame of lodge in which maple sap is boiled, and lodge in which sugar-making utensils are stored. Photograph by Miss Densmore.

winnowing, and threshing. A boat was poled through the rice field and the rice gathered by knocking the kernels from the stalk with two short sticks, the kernels falling into the boat (fig. 97). The rice was then parched in an iron kettle over a slow fire, being constantly stirred to prevent scorching (fig. 98). The next phase of the work consisted in pounding the rice in a barrel sunk in the ground, long, heavy poles being used for the purpose. This loosened the husks, which were removed by winnowing in birchbark trays and threshing with the moccasined feet in a shallow receptacle.

The process of taking seines from the water and drying and preparing fish was observed and photographed, and a maple sugar camp was visited, though not seen in actual operation (fig. 99).

Dwellings and their native equipment were given detailed study, the principal types noted by earlier observers being seen and photographed. The reeds and rushes used in weaving mats for the floor and sides of dwellings were collected, together with specimens of the mats and the implements used in their weaving (fig. 100). These mats are still made by the Chippewa, although the use of native



FIG. 100.—Chippewa woman weaving small mat of rushes.
Photograph by Miss Densmore.

dyes for coloring them has been discontinued. The formulæ for many shades of color were, however, obtainable, and rushes, porcupine quills, yarn, and woolen cloth were dyed by Chippewa women as examples of native ability in this art. Numerous specimens of beadwork in geometric designs were collected, the women stating that these designs were employed by them before the floral patterns which are now in general use. The implements used in the handi-

craft of both men and women formed part of the objective material collected for illustrating this report. The making of birchbark

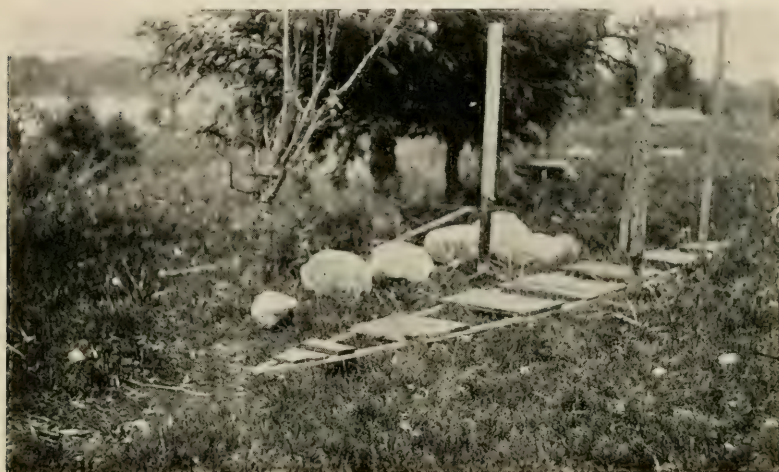


FIG. 101.—Frame on which birchbark canoe is made. Photograph by Miss Densmore.



FIG. 102.—Process of making a birchbark canoe. Photograph by Miss Densmore.

utensils in graceful outlines is rapidly becoming a lost art among the Chippewa, and many examples of this work were obtained.

As the Chippewa were a people living in the woods and beside the water a study of their early life necessarily included the making of a birchbark canoe. For this purpose an old canoe maker was visited and his equipment photographed. Briefly described, the process consisted in molding thick sheets of birchbark upward around a removable flat frame which was held in place by heavy stones (figs. 101, 102). The sheets of bark were sewed together with split roots and fastened to a permanent binding at the top, the seams being calked with spruce or other gum. Hunting and trapping were studied, together with the manner of tanning large and small hides. Games and pastimes were recorded and the implements used in the various games were obtained. Tribal organization received some attention, as well as tribal customs relating to marriage, home life, death, and burial. Not least in importance was the additional information secured concerning the beliefs and customs of the *Midewiwin*, and the practice of good and evil charms.

ETHNOLOGIC WORK IN LOUISIANA

The field-work of Dr. John R. Swanton, of the Bureau of American Ethnology, during 1917, was confined to a short expedition to



FIG. 103.—Mixed Houma Indians, Little Barataria Bayou.

Louisiana between May 16 and June 25. In this period three separate investigations were undertaken. The first of these was a visit to the mixed-blood Houma Indians in La Fourche parish and the

eastern part of Terre Bonne. Dr. Swanton was accompanied and his work greatly facilitated by Mr. Ernest Coycault, a creole living in New Orleans and married to one of these Indians. The brother-



FIG. 104.—Cut-off at site of old Houma village, Point au Chien, La.



FIG. 105.—Method of constructing a palmetto roof. Indian house at Point au Chien, Terre Bonne, La.

in-law of Mr. Coycault acted as pilot, guiding Dr. Swanton to all of the more important Indian settlements between New Orleans and Point au Chien where the oldest Houma town in the region is said to have been situated until destroyed by three huge waves from the



FIG. 106.—Mixed Houma Indians (French, German, and Houma), lower Bayou La Fourche, La.

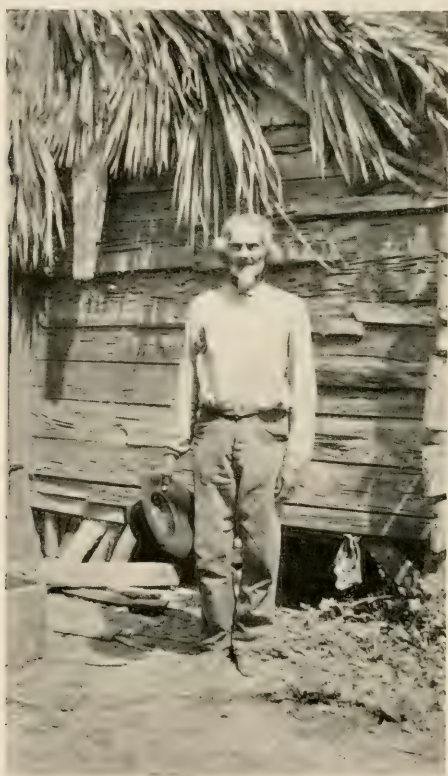


FIG. 107.—Houma man, lower Bayou La Fourche, La. His grandmothers on both sides were Houma, his father's father a German, his mother's father a Frenchman.

Gulf about 1909. A few notes, relating chiefly to the material culture of the people, were made and a number of photographs were taken, but only a single expression in the old Houma language could be secured, and it is evident that the vocabulary obtained in 1907 from an old woman belonging to the western settlements of these Indians is all relating to their language that can now be expected from them.



FIG. 108.—Estelle Sandress, one of the four surviving speakers of Chitimacha.

Before setting out on this trip Dr. Swanton spent a few days in New Orleans examining some of the manuscripts belonging to the Louisiana Historical Society now preserved in the Cabildo, and was able to add several items to his material on the history of the southeastern Indians. His success in this work was much aided by Miss Carrie S. Freret, who has immediate charge of the manuscripts.



FIG. 109.—Chitimacha Indians living near Charenton, La. The man is one of the four surviving speakers of the Chitimacha language. His name is Regist Dardin.



FIG. 110.—Koasati Indians near Kinder, La.

After returning from the Houma Dr. Swanton proceeded to Charenton, La., where he spent a few days revising some of his material on the Chitimacha language with Benjamin Paul, one of the four surviving speakers of this tongue and a man who had assisted him on previous visits. Although it was found that there was little new material to be had, Dr. Swanton secured some gram-



FIG. 111.—Mother of my Koasati interpreter and one of my principal informants.

matical information of great value in fixing the proper position of Chitimacha among the languages of the region.

From Charenton he proceeded to Kinder, in Calcasieu parish, where he remained for about two weeks, recording texts from the Koasati Indians just east of that town. The Koasati language is similar

to Alabama, which Dr. Swanton already studied among the Alabama Indians in Polk county, Texas, but more differences were found between the two than it was supposed existed. He recorded about 150 pages of new text material with interlinear translations, and carefully corrected about 125 pages previously obtained in Texas, but found to be corrupted with Alabama expressions.

ETHNOLOGY OF THE IROQUOIS

On March 2, 1917, Mr. J. N. B. Hewitt resumed his field studies of the League of the Iroquois and of kindred matters relating to the ethnology of the Iroquois, near Brantford, Ontario, Canada. At once he took up the textual and literary criticism of the extensive native texts, chiefly in Mohawk, Onondaga, and Cayuga, relating to the founding and to the structure and the purpose of the League or Federation of the Five Tribes of the Iroquois. This work consists in reading over, grammatically correcting, transposing misplaced parts of texts, annotating obscure passages or obsolescent terms, and, where new information shows the need, expanding the texts with new material. The work is very necessary in view of the fact that much of it was recorded hastily from the dictation of untrained native speakers who did not realize the imperative need of repeating a sentence in the same terms in case it must be repeated.

The difficulty of this task may be measurably realized when it is taken into account that these texts aggregate nearly sixty thousand native words or sentences. It is often necessary to read the words and the immediate context over several times in order to decide upon their tentative final form; this is in addition to the reading of the entire topic or "chapter." An example will suffice. In the Eulogy of the Founders of the League occurs an expression which had been recorded in all previous texts in such manner that it was translated, "The Institution became aged or ancient," or "The Institution has become useless from age." But the correct text, thus found, signifies, "It causes the Institution to become ancient or aged," or "The Institution is being caused thereby to become old or ancient." An important distinction, because it does not state the fact that the League has become old, but rather that the noted causes tend to make it grow ancient or aged. These texts are read over with every well-informed informant in order to elicit a full expression of the informant's knowledge or criticism of the value and correctness of the work of another.

These detailed investigations naturally led to the recording of other corrective or amplifying texts and notes; these amount to over 500 manuscript pages, of which Shaman Joshua Buck supplied more than 240 pages and Emeritus Chief Abram Charles over 260 pages, together on more than forty topics; both these informants recited a ritual for recording.

In addition to this new material in text Mr. Hewitt recorded in English only, three short traditions, about 50 manuscript pages, which though very short are highly significant as they purport to relate events and express ideas and newer conceptions of life and man which, asserting the brotherhood and the fellowship of all men in contradistinction to the ideas of mere tribalism, shaped the principles upon which the League of the Iroquois was built.

Mr. Hewitt also made several important discoveries concerning certain clans of the Iroquois. In brief, the new information shows that three so-called "clans" of this group of tribes do not exist outside of the names which are employed to designate them. It is found that the Onondaga "Ball" clan is in fact a Hawk clan; and that the so-called "Hand" clan of the Cayuga is the Gray Wolf clan; and that the "Potato" clan of the Cayuga and Mohawk (Canadian?) is in fact a (?) Duck clan, or possibly a (?) Wolf clan (the identification is still incomplete). This confusion is due to popular acceptance of a sobriquet as the real name of the clan.

On March 13, Mr. Hewitt was fortunate in being selected as an official delegate from the Council of the Six Nations of Iroquois to represent the Seneca tribe as a celebrant in its behalf in a Condolence and Installation Ceremony held in behalf of the Oneida of Muncietown, Ontario, in which he was required to act a leading part in the rites, necessitating the intoning of an address of comforting in the Onondaga language and also in acting the part of the Seneca chiefs in such a Council of Condolence and Installation. This official recognition gave Mr. Hewitt the rare opportunity of seeing just how such a ceremony is conducted from behind the scenes.

It was Mr. Hewitt's good fortune to obtain a set of wooden masks of the various Wind Gods or Spirits and also two of the Food Gods, eight in all; these Wind Spirits or Gods are held in high repute in the medical circles of these noted tribes.

Mr. Hewitt was also pleased to obtain by purchase the gourd rattle used by the late Chief John Buck, the noted father of his assistant, Mr. Joshua Buck; he also purchased what is reported to be the last cradle-board on the reservation; it has a beautiful beaded belt. He also obtained a fine medicine flute.

PREHISTORIC RUINS IN SOUTHWESTERN COLORADO AND
SOUTHEASTERN UTAH

The country south and southwest of Dolores, Colorado, contains many evidences of a considerable population in prehistoric times. The most striking of these evidences are mounds of stones, remains of well-constructed buildings, the standing walls of which sometimes rise many feet above the surface. Some of these remains are mentioned or described by Newberry, Jackson, Holmes, Morgan, Morley, Moorehead, Prudden, and Kidder, but a still greater number remain unrecorded, although reported by cowboys and sheep herders, who,



FIG. 112.—Lone Pine House, cliff-dwelling near Dolores. Photograph by J. Wirsula.

while paying only casual attention to them, know their sites and something of their superficial characters.

The growing interest in the antiquities of this part of Colorado, especially those of the Mesa Verde National Park, not far distant, has stimulated a desire to investigate other ancient ruins in the neighborhood, and with that end in view Dr. J. Walter Fewkes, ethnologist, devoted several weeks of the autumn of 1917 to an archeological examination of this region. He visited all ruins previously recorded and was able to add several others to the list, without covering more than a part of the extensive territory.

The main object of this work, all too inadequate on account of limited time, was to gather facts bearing on the distribution of prehistoric inhabitants in southwestern Colorado and their cultural rela-



FIG. 113.—Surouaro, situated at the head of Yellow Jacket. Photograph by J. Wirsula.



FIG. 114.—Semicircular tower opposite mouth of Dawson Canyon. Photograph by J. Wirsula.

tionships to those of Mesa Verde, where there is so much in this line to attract tourists and students. Dolores, a station on the Denver and Rio Grande Railroad, was chosen as a convenient point of departure for this preliminary reconnaissance.

Especial attention was paid to a determination of the forms and architectural characteristics of prehistoric buildings. Although no extensive excavations were attempted an examination was made of local collections of pottery and other objects, said to have come from these ruins, as a basis of comparison with similar objects from the Mesa Verde. While collections of these specimens are small they support the conclusion, taught by architectural evidences, that



FIG. 115.—Semicircular tower one mile from Littrell Ranch, Yellow Jacket.
Photograph by J. Wirsula.

the life of the inhabitants of the two regions was similar. They uphold the theory that the final abandonment of the region by the aboriginal occupants occurred in prehistoric times or before the Spanish occupation, but they contribute little to definite knowledge of the date of their construction. In the limited time at his disposal Dr. Fewkes confined his studies to typical ruins situated in an area bounded on the west by the Yellow Jacket, formerly known as the Hovenweep Canyon, and its tributaries; on the south by the McElmo; on the north by a line drawn from Dolores to the head of Sandstone Canyon; and on the east by the Montezuma Valley, which extends from Dolores to Aztec Spring Ruin. In this area there occur many types of aboriginal remains, as open sky pueblos like Far View House, single roomed towers, multi-chambered, massive-walled castel-

late buildings, cliff-houses, and other domiciles. In the progress of this work one or two excursions were made into Utah to Cross Canyon west of the Yellow Jacket, where extensive ruins of characteristic type await investigation, but no attempt is made to include the results of these trips in this account. Naturally, since the eastern part of the area considered has been thickly settled by white men for a considerable time the prehistoric ruins in this region are more dilapidated than those on the public domain farther west. There appears, however, to have been a close similarity in the buildings of the eastern and western parts of the area; existing differences being due rather to nature of sites than to cultural causes. The



FIG. 116.—Aztec Springs Ruin. Photograph by J. Wirsula.

western ruins are the better preserved, and can be used to interpret the buried walls of eastern mounds, where little now remains visible except piles of fallen stones, but a satisfactory interpretation must await verification by the uncovering of their walls.

Aside from one or two cliff-dwellings (fig. 112) the ruins near Dolores crown low hills on the left bank of the river, and are much dilapidated. If they are compared with ruins in the Hovenweep it appears that their buried walls had circular D-shaped forms. One of these hill-ruins situated about three miles from town, in plain sight from the Monticello road that practically follows the old Spanish trail, is the ruin referred to in the brief notice that appears in the diary of Fathers Dominguez and Escalante, dated 1776, and is probably the first Colorado ruin mentioned in historical documents.

Another pile of stones (fig. 113), called Surouaro by Professor Newberry, is situated on the same road 14 miles west of Dolores, at Yellow Jacket Springs. According to this author it takes its name from an Indian word meaning desolation, but the name, unknown to ranchmen, is not now appropriate, for modern dry farmers are raising crops in its neighborhood equal to any in Colorado.

There are very extensive ruins all along the rim of Yellow Jacket, the largest of which, nearly opposite Dawson Canyon (fig. 114), is 5 miles south of Surouaro. Its walls, accompanied by a D-shaped tower (fig. 115) perched on a shelf halfway down the canyon, are well preserved and about 15 feet high. There is a similar semi-circular tower a few miles away.



FIG. 117.—Mud Spring Ruin. Photograph by J. Wirsula.

The portion of Montezuma Valley at the mouth of the McElmo is irrigated by water drawn through a tunnel from the Dolores River, the waste flowing down the McElmo. The surface of the valley slopes uniformly southward and is destitute of canyons, but cut by several deep arroyos. In general the ruins of this valley are villages or clusters of mounds one of which is more prominent than the others.

One of the largest and most typical is called Aztec Springs Ruin (fig. 116), described by Holmes many years ago. Its striking feature is the large rectangular mound indicating a block of rooms, or "Upper House," which contained two large, circular, central kivas and one small circular kiva, surrounded by rectangular rooms forming

a compact pueblo of the pure type. The "Lower House" is a rectangular enclosure surrounded on the east, west, and south sides by a low wall and with rows of rooms on the north side, enclosing



FIG. 118.—Goodman Point Ruin. Photograph by J. Wirsula.



FIG. 119.—Blanchard Ruin. Photograph by J. Wirsula.

a circular depression or reservoir. Around the former are several mounds, remains of former blocks of buildings with kivas, the walls of which have fallen.

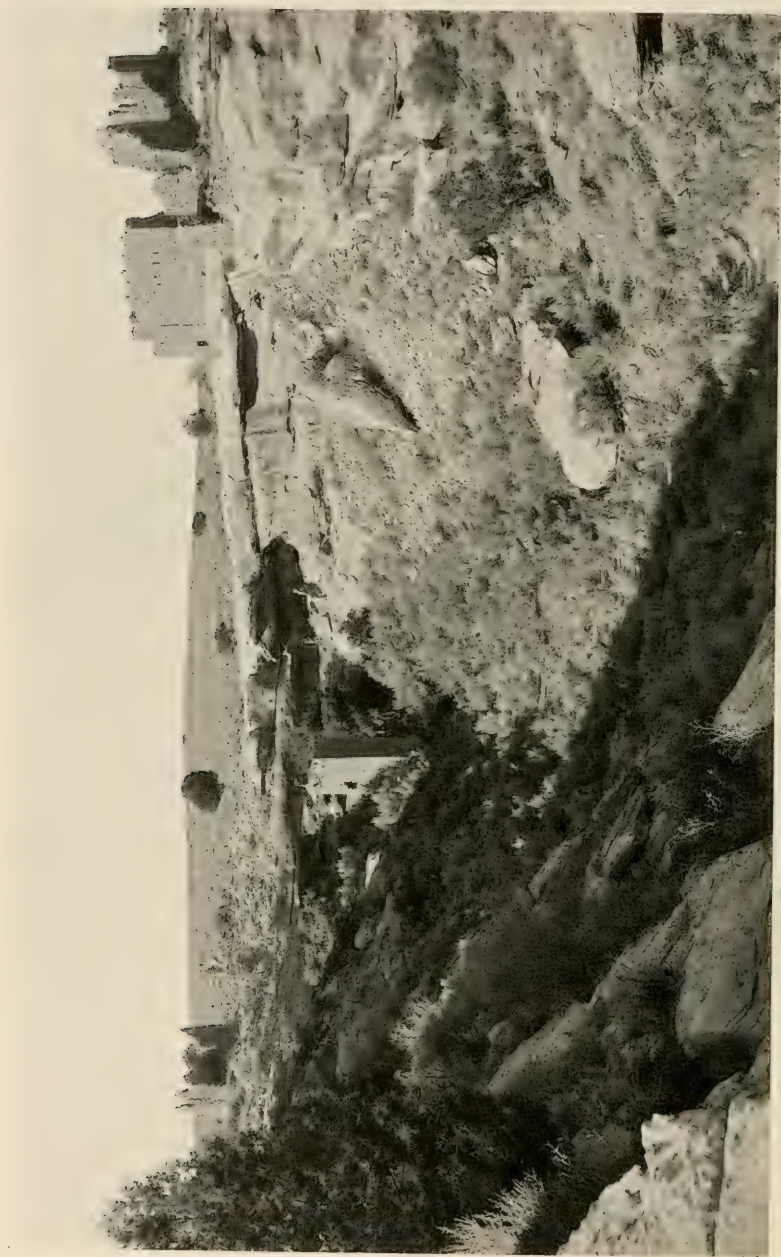


FIG. 120.—Towers at head of Square Tower Canyon. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.



FIG. 121.—Towers at head of Square Tower Canyon. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.



FIG. 122.—Towers in Square Tower Canyon. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.

The Mitchell Spring Ruin, situated at Old Town or Toltec, 3 miles south of Cortez, first described by Morgan, resembles in type that mentioned above, and consists of several mounds or remains of rectangular buildings and a tower. One of the smaller of these mounds, excavated by Dr. Prudden, had a central circular kiva surrounded by rooms, constructed like those of Far View House.

The same arrangement of mounds in clusters or villages found at Aztec Springs Ruin and Mitchell Spring Ruin occurs also at Mud Spring Ruin (fig. 117), 7 miles from Cortez, at the head of McElmo Canyon. The mounds are numerous and cover a considerable area. The two largest are separated by a gulch in which lies a spring, as at Aztec Springs Ruin. In one of the largest mounds is the so-called "triple-walled tower" (Holmes) with concentric walls, embedded in rectangular rooms.

There are several other ruins of the clustered mound or village type in the Montezuma Valley, but in many the smaller mounds have disappeared under cultivation of the land. Among these may be mentioned Goodman Point Ruin (fig. 118), and that on the Blanchard Ranch (fig. 119), stones from which were removed to Manitou a few years ago to construct a cliff-house in imitation of Cliff Palace and Sprucetree House. None of the stones used in the construction of the Manitou reproduction came from Mesa Verde.

The Wolley Ranch Ruin, about 10 miles south of Dolores, is a good example of a pure pueblo type of ruin. About all that remains of a former cluster of mounds is the largest, now so overgrown with bushes that architectural details are difficult to observe, but there are evidences that it was a rectangular building with enclosed circular kivas, but without courts or passageways.

In their general features the groups of mounds in the Montezuma Valley resemble the cluster at Mummy Lake, on the Mesa Verde, both in arrangement and in their individual structure, so far as can be judged from the desultory excavations by which walls have been brought to light. Each mound in a cluster has the same structure as the pure type found in Far View House. The top courses of the walls have fallen and filled the rooms with stones and earth. The cemeteries commonly situated east and south of the mounds have nearly all been rifled of their contents. Certain mounds in the cluster may be remains of towers; others of "great houses"; and the same may also be said of different members of the Mummy Lake group.

This same clustering of mounds, characteristic of the Montezuma Valley ruins, occurs also in those situated in the broken country



FIG. 123.—Twin Towers, Square Tower group. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.

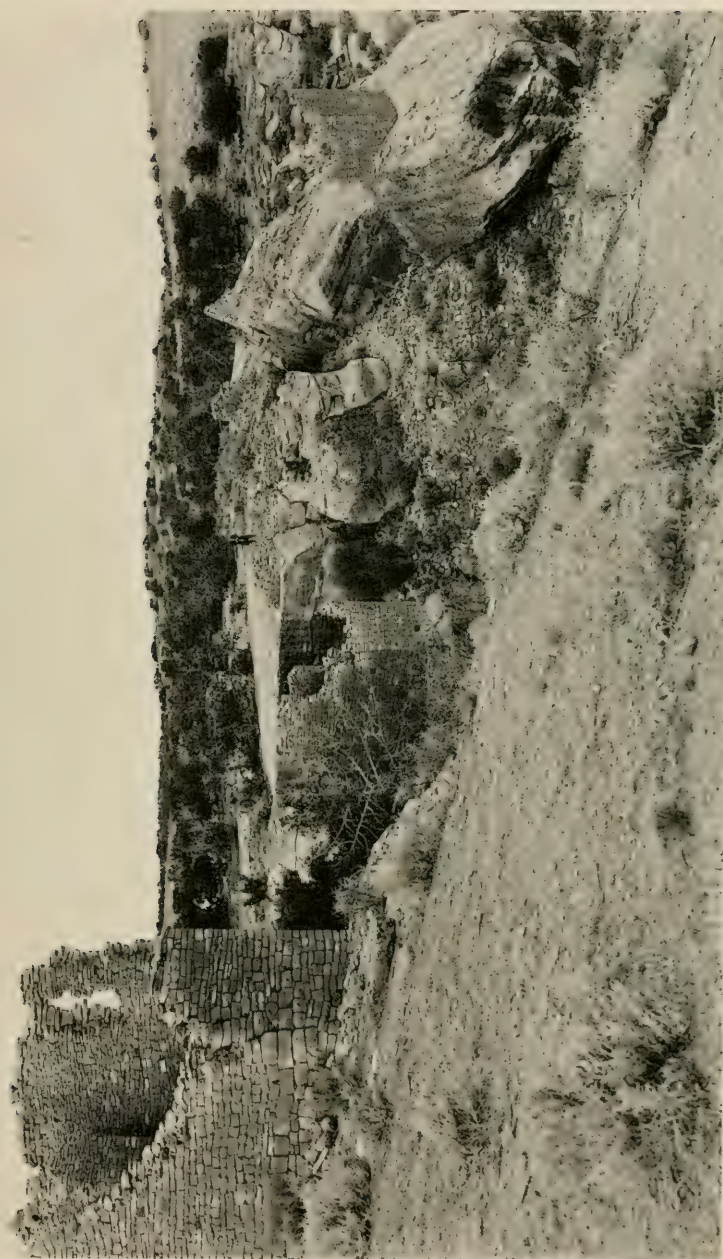


FIG. 124.—Group of Ruins in Holly Canyon. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.

cut by the deep canyons that open into the McElmo, west of this valley, although the arrangement of the mounds is modified by configuration of the sites or adjacency of springs. As a rule the mounds

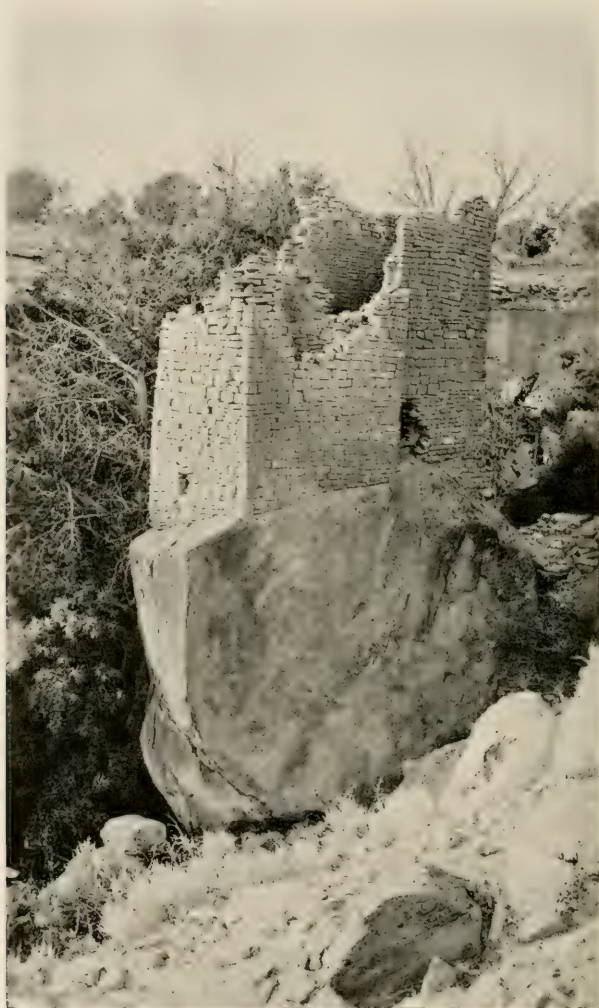


FIG. 125.—Tower in Holly Canyon. Photograph by J. Wirsula.

or clusters in this region either skirt the canyon rims or cluster about their heads. They are generally accompanied with large towers and buildings of the "great house" type (figs. 120 and 121)

situated on points of the mesa rim or perched on fallen angular rocks on the floor of the canyon. It may be mentioned that their walls are constructed of good masonry, which has effectually resisted the erosive power of the elements.



FIG. 126.—Group of ruins in Holly Canyon. Photograph by J. Wirsula.



FIG. 127.—Horseshoe Ruin, Hackberry group. Photograph by J. Wirsula.

The early builders were prone to introduce curved walls in these buildings; they were partial to circular, oval, and D-shaped structures, although square and rectangular buildings are common. They paid little attention to leveling the foundations on which the walls

were constructed, but inequalities in the base were built up with flat stones to the level of the lowest courses. The stones used were of different sizes, well trimmed by means of stone implements. The walls remain fairly stable, notwithstanding the foundations on which they rest are very uneven.

The cliff-dwellings and pueblos of the Mesa Verde National Park belong architecturally to the "pure type," the characteristic of which is a compact pueblo with a circular kiva with mural banquettes and pilasters that formerly supported a vaulted roof, a ventilator with air passage and deflector, and generally a ceremonial floor opening called the *sipapu*. The same type of kiva has been observed in the great consolidated pueblos of the Chaco and the cliff-dwellings in the Chelly Canyon. Dr. Prudden, Dr. Kidder, and Mr. Morley have recorded this type from ruins in Montezuma Valley and the McElmo-Yellow Jacket and Montezuma Canyon regions, and Dr. Fewkes discovered last summer that it occurs in several pueblos of the Hovenweep district. The existence of this form of kiva beyond the limits of the Mesa Verde marks the extension of the prehistoric area it characterizes.

Three groups of large, well-preserved buildings illustrating most of the types of the Yellow Jacket district occur between 40 and 50 miles from Dolores in a limited area which Dr. Fewkes suggests be made by proclamation a National monument, to be known as the Hovenweep National Monument. These groups are as follows: 1. Cluster at the head of Square Tower (Ruin) Canyon (figs. 121, 122 and 123); 2. Holly Canyon group (figs. 124, 125 and 126); 3. Hackberry (branch of Bridge) Canyon cluster (fig. 127). The three regions lie a few miles apart, not far from where the Yellow Jacket empties into the McElmo, near the Utah-Colorado State line. The structure of the well-preserved buildings in these groups enables us to interpret the probable appearance of the buildings, now mounds, in the Montezuma Valley.

In the first-mentioned cluster there are 11 different buildings within a radius of half a mile. One of these, Hovenweep Castle, (fig. 128), has walls that measure 66 feet long and 20 feet high. This building has, in addition to towers and great rooms, two circular kivas on the east end, identical in construction with those of Far View House on the Mesa Verde.

Some of the so-called towers, as figure 130, have single, others multiple, chambers, and are generally two or three stories high. Their shapes are rectangular, circular, semicircular, D-shaped or oval.

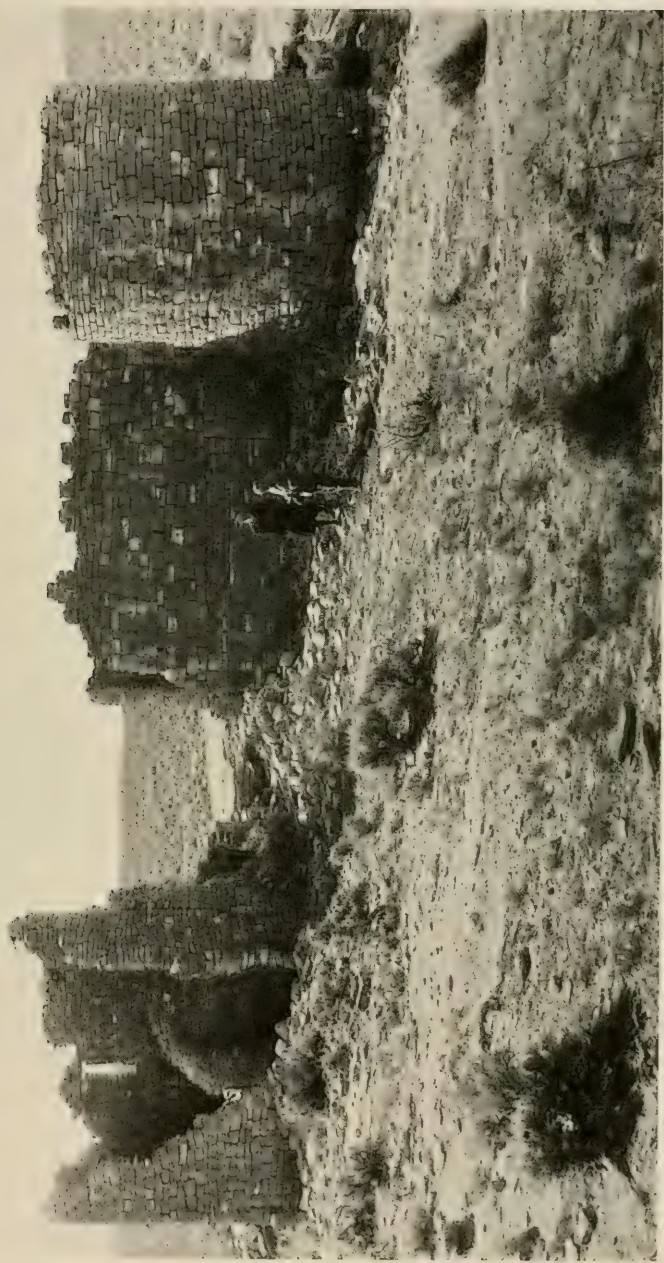


FIG. 128.—Hovenweep Castle. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.

One of the most instructive buildings in the Square Tower group (fig. 131) is Unit Type House, a pueblo having a single centrally placed kiva, identical with the kivas of Far View House, compactly surrounded by rectangular rooms, rendering them subterranean and imparting to the ruin a square form (fig. 132). This kiva is characteristic of the pure type of pueblo, whose close likeness to Far View House shows the identity of architectural forms among the prehistoric people of the Mesa Verde and McElmo.



FIG. 129.—Model of Hovenweep Castle.

The cliff-dwellings in Square Tower Canyon are small; one of these was constructed in the eroded cave of a fallen rock, part of which arches over the walls, forming a roof. There is a small chamber in a cave under the two large buildings called the "Twin Towers." The largest cliff-house in this canyon is situated at its head, but unfortunately its walls are now considerably demolished.

Great House, one of the buildings in the Holly Canyon group (figs. 133, 134), about a mile east of Keeley Camp, has the highest walls in these great houses. Five large buildings cluster around

the rim of a spur of this canyon or are perched on angular rocks at its base. Even now, after centuries of wear, they show fine masonry, although some of the mortar between the courses of stones



FIG. 130.—Tower in Holly Canyon. Photograph by J. Wirsula.

has been washed out. There are small cliff-houses in the walls of the canyon below these great houses.

An instructive cluster of ruins in the Hovenweep district is the Hackberry Canyon group situated about 2 miles east of Keeley

Camp, or a mile beyond the cluster on Holly Canyon, above mentioned. One of the members of this group from its shape is called the Horseshoe House. This ruin (fig. 135) has two concentric walls, a curved outer one on the north separated by about 4 feet from an inner circular wall and united to it by two radial partitions forming compartments still well preserved. The height of the outer wall is 12 feet; that of the inner somewhat less.

Several features of this ruin (fig. 135), besides its D-form, recall Sun Temple on the Mesa Verde. Apparently the entrance was on the south, but the walls on this side have fallen, although traces



FIG. 131.—Unit Type House, Square Tower group.
Photograph by J. Wirsula.

still remain of the inner wall. The south wall of the southeast compartment is still erect but does not connect across the south side of the building. Apparently the southwest compartment ended in the same way as the southeast, but as the wall has fallen there is no evidence of a row of rooms across the south side.

There are half-fallen walls of a cliff-dwelling (fig. 136) of considerable size in a cave situated below this building, and upon a neighboring point stands a square tower with high walls and curved corners. Attention may be called to the fact that here, as elsewhere, wherever we find these large buildings on the rim of the canyon there

exist also dugouts or cliff-houses suggesting habitations in the cliffs below.

Several great houses of the Hovenweep belong to a prehistoric type distinct from pueblos, for nothing similar to the multichambered "great house" is found in modern pueblos, although the one-chambered tower may be the same as extramural circular kivas in

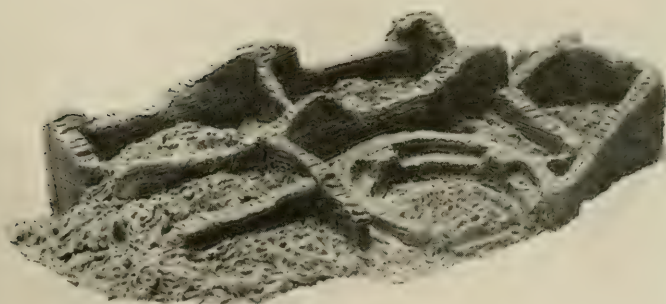


FIG. 132.—Model of Unit Type House.

the Rio Grande pueblos. Whether towers are one or many chambered, in form circular, oval, D-shaped, or square buildings, isolated, or united to pueblos, or whether towers and great houses belong to the same type, is not evident. These great houses or so-called towers with several rooms could hardly have the same use as circular or square towers with one room. They do not suggest habitations, and the number of workmen necessary to build them would be

large for them to accommodate. Their general appearance suggests granaries, forts, castles, or some communal use; possibly they were religious buildings. Like certain towers, they are sometimes too shut in by surrounding cliffs to serve as lookouts; they are accompanied by cliff-dwellings which show evidences of habitation. Evidently these large buildings with several rooms without kivas not



FIG. 133.—Great House, Holly Canyon. Photograph by T. G. Lemmon.

only belong to a specialized architectural type but also to a localized one. This type is different from the pure pueblo type, mainly in the absence of terraces and central, circular kivas surrounded by rectangular rooms; it resembles buildings like Casa Grande. When towers are united to a building of the pure pueblo type, as shown in Hovenweep house of the Square Tower (Ruin) Canyon, we have a building made up of two united types, the most complicated form of pueblo architecture.

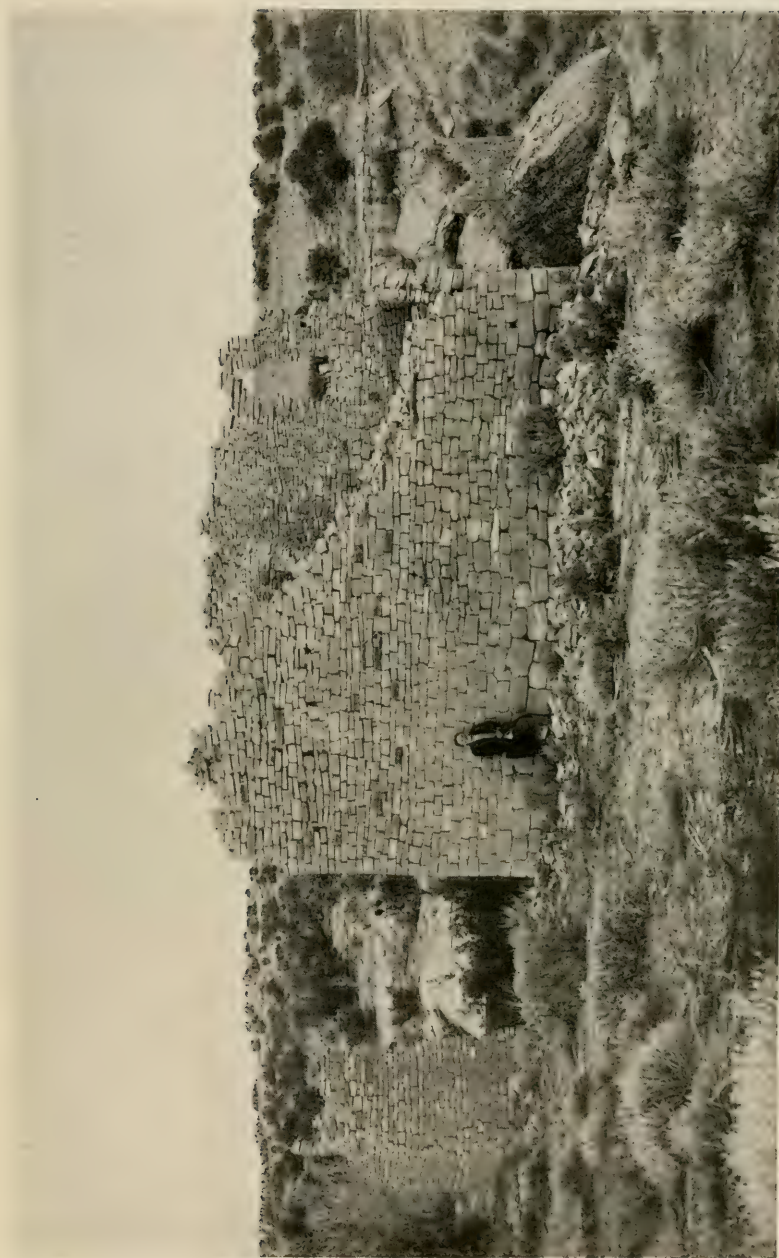


FIG. 134.—Great House, Holly Canyon. Courtesy of Denver and Rio Grande Railroad. Photograph by G. L. Beam.

One feature of many open-sky ruins of the Yellow Jacket which distinguishes them from Mesa Verde ruins is their site. They arise at the heads of canyons or along the rim rock, while as a rule the Mesa Verde pueblos, like Far View House, are situated some distance from the edge of the canyon, like some ruins in the Yellow Jacket series.

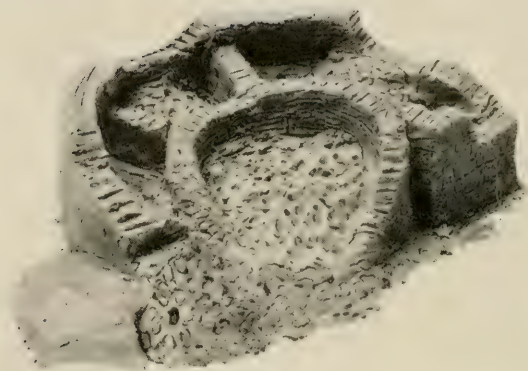


FIG. 135.—Model of Horseshoe Ruin.

The simple, isolated towers in the Mesa Verde resemble those of the Hovenweep, but there are many mounds on Mesa Verde awaiting excavation where there was probably a union of towers and pueblos.

The walls of the "great house" type of this region show less wear by the elements than those of the open-sky buildings on the Mesa Verde. As the destruction by atmospheric causes must have been about the same, year by year, in the two regions, it would be natural

to conclude that the Mesa Verde pueblos were deserted earlier than the McElmo, or that the latter were constructed later, either of which suppositions has a bearing on the chronology of the prehistoric culture in the San Juan Valley. By the same reasoning the consolidated villages of pure type like Aztec would be regarded as more modern than the pueblos of the Mesa Verde.

Another feature in the Yellow Jacket Canyon ruin, as compared with the Chaco and other great pueblos situated near the horizon of the pure type in New Mexico, may be significant. Castellate buildings referable to the "great house" type have not been recorded south of

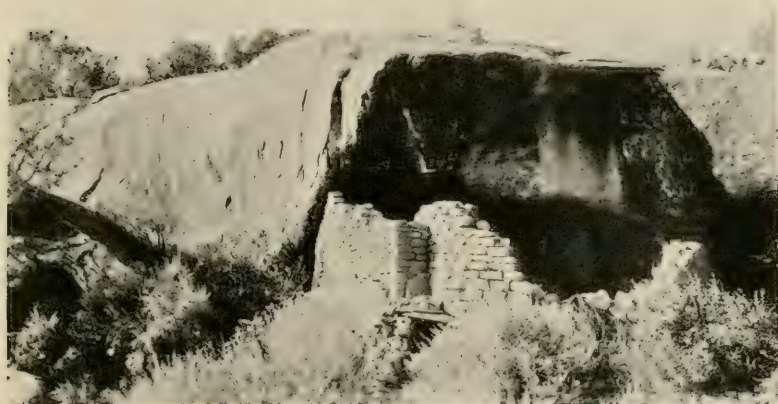


FIG. 136.—Cliff-dwelling, Hackberry group. Photograph by J. Wirsula.

the San Juan; towers are found, but they are less numerous. These types in the San Juan region, each specialized for specific purposes, when contrasted with the uniformity in the architecture of historic pueblos in New Mexico, are likewise significant. The "great house," like the "pure type," is prehistoric; nothing comparable to it has been identified in modern pueblos.

It is pretty generally believed that, in order to support the large population implied by the number and size of these McElmo-Yellow Jacket ruins, their farms on neighboring mesas were formerly better watered. The conclusion is sometimes reached that there has been a climatic change or desiccation that has driven out the aboriginal dry farmer. Attention, however, should be called to the fact that American dry farmers are now successfully cultivating these pre-

historic farms, one source of moisture being now, as in prehistoric times, melting snows. Absence of snow and rain for several consecutive years might have reduced their crops and starved the aboriginal dry farmers, even though a permanent change of climate did not occur.

To utilize their limited water supply the aborigines constructed many reservoirs near their farms to retain snow and rain. These are now indicated by sloping rock surfaces, bare of soil but girt with



FIG. 137.—Prehistoric reservoir, near Hovenweep Ruins.
Photograph by T. G. Lemmon.

vegetation; about the lower edge the natives constructed a low bank of earth to serve as a retaining wall. It is estimated that one of these reservoirs (fig. 137) covers a surface of 4 acres; others are still used by herdsmen, who have somewhat increased the height of the retaining walls, for watering stock.

We find near ruins in this region many examples of enclosures made with slabs of stone set on edge. The use of these structures has not been satisfactorily explained; they have been variously interpreted as graves, crematory cists, and storage places or pits for

roasting corn. The majority show scanty evidences that they were graves, and excavations have yielded few, if any, human bones, although ashes and charcoal are abundant. Similar slabs of stone, possibly a survival of a more archaic method of construction, are often found set upright in horizontal masonry. Some of these uncut stones are large enough to be called megaliths; these also may be regarded as survivals of early methods of construction; in some walls they are used without smaller stones.

The Director of the National Park Service, recognizing the popular and scientific interest in the preservation of the towers in Square Tower (Ruin), Holly, and Hackberry Canyons, as a sequel to the above field work, is endeavoring to have them set aside from the public domain, to be known as the Hovenweep National Monument.



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